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**A SYSTEMS ENGINEERING DECISION ALGORITHM WITH  
APPLICATION TO APOLLO APPLICATIONS  
PROGRAM INTEGRATION PROBLEMS**

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16. Abstract  A decision algorithm, that has been specifically adapted to the needs of the System Engineer, is presented for resolving complex Apollo Applications Program (AAP) technical and management integration problems. An explanation of decision theory as applied to a technical problem and a detailed example of how the decision algorithm was used to determine the best location for the Scientific Airlock in either the Orbital Assembly's Airlock Module Structural Transition Section, or the Multiple Docking Adapter is submitted.  It is concluded that alternate position number 1, located on the Structural Transition Section, be chosen to resolve the AAP technical, operational, and management requirement problems. Further, it is concluded that the decision algorithm can be used to address many complex systems engineering problems requiring timely and accurate decisions.			
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## LIST OF SYMBOLS

<u>Symbol</u>	<u>Definition</u>
AAP	Apollo Applications Program
AM	Airlock Module
ATM	Apollo Telescope Mount
$C_{ij}$	A statement of outcome (consequences)
CSM	Command Service Module
ECS	Environmental Control System
IVA	Intravehicular Activity
LM	Lunar Module
MDA	Multiple Docking Adapter
OA	Orbital Assembly
O/B	Outboard
RCS	Reaction Control Packages
SAL	Scientific Airlock
STS	Structural Transition Section
TBD	To be determined
→	. . . more important than . . . . , indicates preference

## A SYSTEMS ENGINEERING DECISION ALGORITHM WITH APPLICATION TO APOLLO APPLICATIONS PROGRAM INTEGRATION PROBLEMS

### SUMMARY

Every engineer or manager who is associated with the development and evaluation of an engineering design is faced with making a number of decisions regarding the acceptance or rejection of a design approach. Some decision considerations may be critical while others are insignificant. Knowing how to structure a decision problem and what considerations to make is the intent of this internal note. This document presents the systems engineering work performed on the development of a decision algorithm for application to AAP integration problems. This document describes the elements of a decision situation, how to state primary objectives, and how to develop a list of solution attributes. Methods for ranking solution attributes or obtaining utility curves, synthesizing solution alternatives, and means for evaluating the candidate solution alternatives are also included. Provision is also made for analyzing alternative solutions for adverse consequences and for selecting solution alternatives that satisfy a decision criterion.

The appendices to this document present a sample decision problem that demonstrates how the algorithm is applied and interpreted. The sample problem was constructed around the design requirement for selecting one of four alternate Scientific Airlock (SAL) locations. The SAL was to be located on either the Multiple Docking Adapter (MDA) or Airlock Module/Structural Transition Section (AM/STS).

### INTRODUCTION

Decision theory is concerned with the methodologies for aiding the decision maker in the process of making or improving decisions under conditions of both certainty and uncertainty. The objective of these methods is to allow the decision maker, when confronted with a complex situation with many

alternatives and consequences, to identify a course of action that is consistent with both his requirements and philosophy.

Complex decision making situations continuously arise when using the systems engineering development process. These decision situations usually present themselves in the form of a system, subsystem, or component to be designed, as a process to be developed, or as a task to be accomplished. The solutions to the decision situations usually present themselves in the form of alternative courses of action, any one of which could possibly be satisfactory. The real problem in the decision making process is how to make a rational choice between the alternatives. Whenever the situation is complex and the alternatives are numerous, the systems engineer's or project manager's task becomes extremely difficult. In actual practice, it is well known that as the volume of data increases, the evaluation of the relevant data becomes less accurate and less consistent. This leads to the omission of important facts, misinterpretations, inconsistencies, biased considerations, errors, and, in the end, selection by sheer prejudice.

The recognition of the decision maker's plight has led to the use of some of the methodologies of formal decision theory in actual engineering practice. The use of these methodologies allows the decision maker to make rational decisions regarding complex situations with greater accuracy, greater confidence, and in a shorter time than was previously possible.

In regard to the decision making methodologies that are available, it must be thoroughly recognized that all decisions ultimately are based upon human judgement and that human judgement is subjective. Unfortunately, it is a historical fact that human judgement is far from perfect; but fortunately, there is an ever-increasing amount of data that indicate that human judgement is quite acceptable when applied in the proper realm and with the proper precautions.

The realm in which the use of human judgement is acceptable is in the expression of opinions and attitudes in the specialty fields for which the person or persons are experts. The list of precautions which must be taken include: (1) the personal type data (opinions, estimates, judgements, etc.) must be acquired only from considered experts; (2) the quantification of this data must be consistent; and (3) the opinions must be restricted to the criteria level considerations and not to the considerations in the large.

It must be emphasized that the decision making methodologies primarily enhance the use of expert opinion as outlined by Churchman, et al. [1], Fishburn [2], and Miller and Starr [3]. Further, it must be emphasized that, aside from divine inspiration, there is no better source of data.

Psychophysical experiments have been conducted which demonstrate that expert opinion can yield valid predictions when the opinions are restricted to relations in the small and then combined into a prediction regarding relations or performance in the large. It is in the combining of the expert opinion into a predictive statement of performance involving complex relations that the decision theory methodologies are the most useful. It must be realized, however, that the decision theory methodologies are based upon certain restrictive assumptions, and when the input data do not conform to the assumptions, the results deviate from reality.

Most of the restrictive assumptions upon which the decision methodologies are based deal with the independence of various dimensions of the decision situation. This independence is required in order to justify the amalgamation of opinions in a linear fashion. This linearity assumption ignores any possible cross-correlation between the dimensions, and the degree to which the cross-correlation is present in a given situation will determine the degree to which the predicted results deviate from reality. This cross-correlation problem can be minimized by keeping the parameters on approximately the same descriptive level.

Decision situations occur with varying levels of complication. These levels are best described for convenience in terms of five distinct levels as presented by Lifson [4].

Level One - The decision maker, aware of the problem, subjectively and intuitively considers alternatives, states, outcomes, probabilities, and utilities, and selects an alternative for implementation. Judgment is applied at the level of the total problem.

Level Two - The decision maker is presented with an explicit set of candidate alternatives. States, outcomes, probabilities, and utilities are subjectively manipulated and a decision is made. Judgment is applied at the level of the set of candidate alternatives.

Level Three - The decision maker is presented with explicit sets of alternatives, states, and the usual measures of outcomes. The decision maker intuitively assigns utilities and probabilities and subjectively manipulates these factors to arrive at a decision. Judgment is applied at the level of outcomes.

Level Four - Alternatives, states, and their probabilities and outcomes measured by their usual dimensions are made explicit and quantitative. Judgment is applied at the level of assigning utilities to the outcomes. At this level, the best alternative can be identified by explicitly computing the relative worth of each alternative.

Level Five - Significant states of the environment and the criteria comprising the measures of outcomes are identified. Furthermore, utilities associated with the measures of each individual criterion are assigned. Judgment is applied at the level of the individual criterion. The utility assignments can, therefore, be made before the set of candidate alternatives is synthesized. The best candidate alternative can be identified by explicitly computing, when each candidate is analyzed and the probabilities to be associated with the measures of outcomes are estimated, relative worth of each candidate alternative.

The decision algorithm described in this report can be applied to Level Four or Level Five decision situations.

## DESCRIPTION OF DECISION SITUATION

The first step in a decision making process is to define the problem as clearly and concisely as possible. (See Functional Block number 1.0, Fig. 1.) An inquiry is begun which examines the state of affairs to determine possible anticipated consequences. The ultimate objective is to select a course of action from a number of promising alternatives that will maximize expected value. Alternatives can be contained in the actions to be taken and the states of nature to be considered. In attempting to formulate and define the problem, one must search out the facts associated with the decision situation. A decision problem is never completely undefinable. Some elements of the problem are clear and fixed. Since some of the elements are fixed in existence, it is possible to fix them in observation as discussed by Hall [5] and Dewey [6]. The facts are derived by analyzing the decision situation to isolate those important outside elements, considerations, and influences which observation suggests are relevant to the problem. The decision situation itself may contain within it possible solutions to the problem.

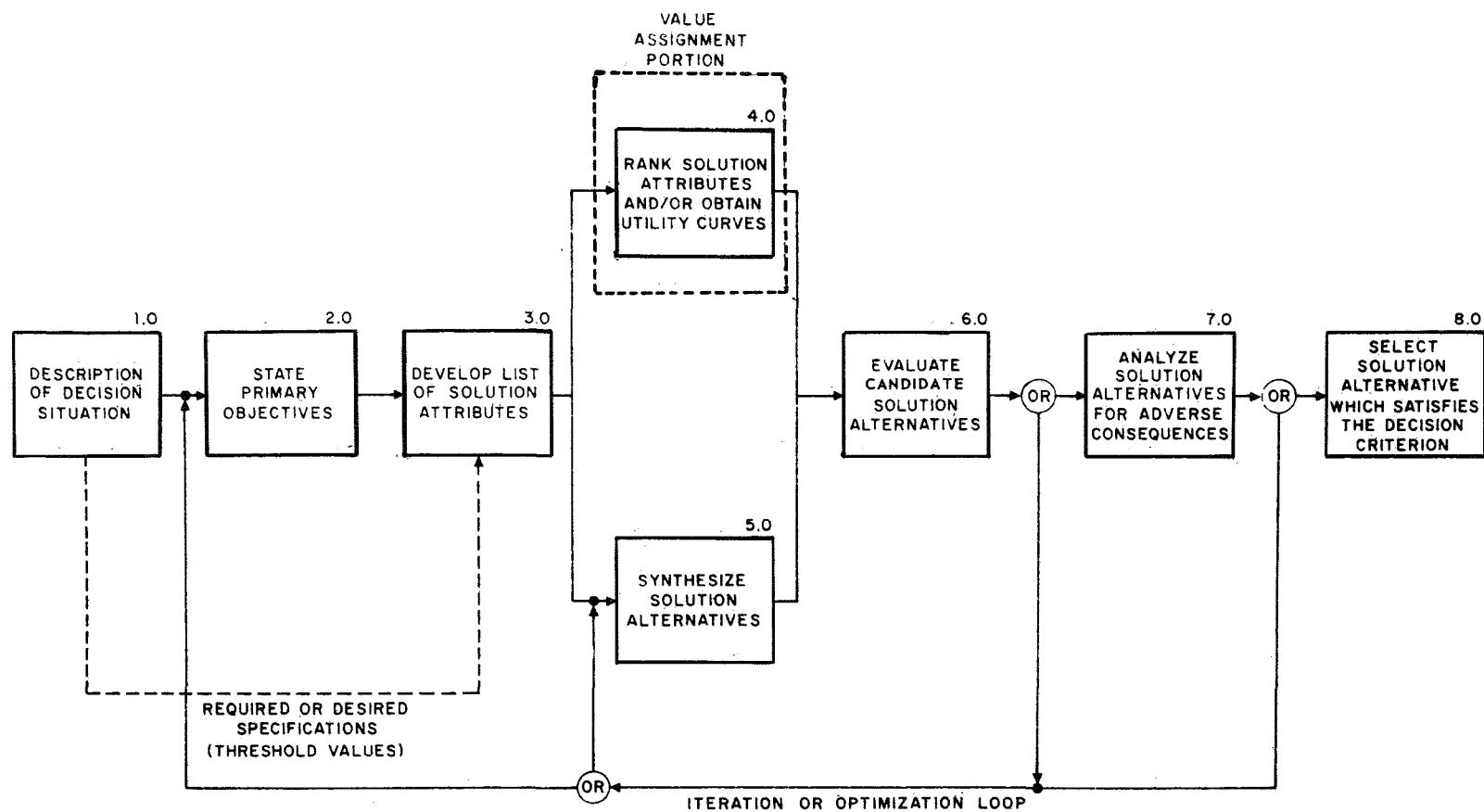


Figure 1. A model of the decision making process.

There are a number of creative methods for analyzing decision situations to present the relevant facts. The approach used in this decision making process employs two research techniques. These research techniques were used to acquire and organize decision situation facts and tentative functional system characteristic statements. A needs research was used to broadly determine what essential and pertinent needs must be met from an engineering, operational, and management standpoint. Furthermore, the needs research was aimed at identifying the expected gains or losses from the input decision situation description, and ascertaining their relative importance as a component (system attribute) to the definition of the problem. In essence, the needs research determined the scope and preciseness of the problem definition statement.

An environmental research was used concurrently with the needs research. The aims of the environmental research were to search out, understand, and describe the environment in which the problem was to be formulated and to predict what tangible and intangible influences might affect the problem situation at some period in time. If the environment is dynamic (i.e., changeable with respect to time), then the problem situation, as well as the problem definition, is also dynamic. Environmental research critically surveys new and relevant ideas, methods, theories, opinions, documented facts, assumptions, formal ground rules, drawings, etc. that might be used in satisfying needs and narrowing a particular set of needs under consideration.

The needs research and environmental research may be considered a correlative activity. Both approaches aim to satisfy needs, but one starts with customer or system needs and the other starts with new end items. Both approaches can be effectively used to identify the customer's immediate and long-range needs. By fulfilling the customer's needs, specific project or program goals can be met. In most cases, the goals are established by the customer, but where goals are not clearly defined, the needs research and environmental research can be used as an aid in the quest to establish goals.

In many instances, questions are raised that ask how various needs will be met, or what the environmental situation for a particular solution is. In the process of answering these questions, the customer may establish new goals or redefine old ones. Every physical system has its own unique goals. A listing of goals that appears most frequently includes profit, safety, compatibility, cost, time, market, flexibility, quality, simplicity, availability, performance, maintenance, commonality, and permanence.

Usually any decision making effort requires the expenditure of human and material resources. The resources usually considered within the scope of a decision problem are the time it takes to make a positive decision, the expenditure or modification of hardware (material), the expenditure of human skills (labor) to accomplish a given task, and the expenditure of capital for the recompense of labor and cost of materials. Even the power to make a decision (authority) is considered an important resource in a decision situation.

Copeland [7] submits that a description of the decision situation is usually characterized by: (1) the desire to reach a particular goal or goals; (2) the availability of several actions that can be taken, some of which will not be as effective as others; and (3) the expression of the environment that exists with respect to the action outcomes — certainty, uncertainty, conflict, risk, and ignorance.

## STATE PRIMARY OBJECTIVES

Once the decision situation is adequately described and the problem areas are clearly understood, it becomes necessary to state the primary objective. (See Functional Block 2.0, Fig. 1.) The development of a primary objective incorporates an editorial statement (who, what, where, when, how, and why) of needs and should describe how the problem goals are to be optimally fulfilled. The primary objective statement provides a standard that can be used as an effectiveness measurement in assessing the available information about any alternative solution or design attributes that an evaluator might consider.

## DEVELOP LIST OF SOLUTION ATTRIBUTES

The third major step in the decision making process is to specify and list the system solution design attributes, hereafter designated "solution attributes." (See Functional Block 3.0, Fig. 1.) Solution attributes are defined as design properties or characteristics (physical — size, weight, color, etc.; performance — speed, range, reliability, etc.; others — cost, scheduling, risk, etc.) that form a composite system or subsystem. Once the decision situation is documented, the relevant information is used in the

process of selecting solution attributes. Since the decision situation identifies the customer's needs, usually defined in terms of design and operational specifications or performance threshold values, it becomes evident that the input specifications and performance design criteria greatly influence the solution attributes. The solution attributes are explicitly stated in terms of wanted physical systems that have some intrinsic value, but the problem situation consideration and requirements strongly influence the value of a system as offered by Chestnut [ 8 ].

The solution attributes are usually defined in terms of desired inputs, expected outputs, boundary conditions, and needs that the system aims to satisfy.

Again, Lifson [ 4 ] submits that the design criteria for the solution attributes may be classified according to: (1) effectiveness — a measurement of needs fulfillment; (2) resources — representing the cost associated with levels of effectiveness; and (3) schedule — representing the time when the system is required. The design criteria, in this instance, are a measure of solution attribute goodness and will eventually be used as an input to the value model. The derived attributes are formulated from a more explicit set of subsystems. The solution attributes are constructed from refined subsystems, detailed design, and expected performance criteria.

## RANK SOLUTION ATTRIBUTES AND OBTAIN UTILITY CURVE

The solution attributes must be classified according to importance to determine what influences they exert on the value model. This is accomplished by ranking the solution attributes and/or by obtaining the associated utility curves for the attributes. (See Functional Block 4.0, Fig. 1.) Before an attribute can be classified as relatively more important than another, the attributes must be evaluated in terms of their individual decision criteria variables. The initial decision situation statement provides some of the criteria variables while others are derived by synthesis and analysis. A decision criterion is usually stated as a functional attribute which one wishes to maximize in a selected alternative. It is stated as a rule that specifies how the consequences are combined to permit the selection of an optimum system. The decision criteria usually specify the values to be gained and the uncertainties associated with the attainment of those values [ 5 ].

At this point, the idea of solution attribute (and their subsystem components) measurement is introduced. The attributes are sometimes measured in money, psychological values, or in discrete engineering quantities (inches, pounds, time, etc.). The attributes and their subsystem variables, especially those used in Appendix A, are measures on the ordinal, interval, and ratio scales. In making any realistic decision concerning value judgement, all the combinations of dimensionality and level of measurement must be accounted for. It must be recognized that almost all complex engineered systems are measured on a multidimensional scale as discussed by Hall [ 5 ], Goode [ 9 ], and Stevens [ 10 ]. It is an elementary fact that the solution attributes and their related subsystem variables are a conglomeration of subjective and objective facts, opinions, ground rules, assumptions, etc. This assortment of criteria, as Duncan and Raiffa [ 11 ] contend, will undoubtedly cause inconsistencies (intransitivities) to arise during the importance ranking of solution attributes and their subsets. One must either resolve the inconsistencies between the attributes or recognize that they exist. In order to effect a comparison of solution attributes, the above scales must be combined and forced into a multidimensional scale. Accordingly, it becomes necessary to adopt a relative weighting technique and assign a proportional utility (importance value) to the solution attributes and their implied subsystems. The use of relative weights permits the comparison of nonhomogeneous attributes and subsystems by placing them on a composite dimensional scale, and establishes a transitive ranking. Sometimes the weighting of the attributes and subsystems is implicit when made by human observers. At other times, an analysis and discussion of a solution attribute can clearly and explicitly reveal the subsystem component variables of a vector and indicate the risk of approximations.

The solution attributes should be carefully inspected to determine if any dominant relationships exist. This judicious consideration can greatly simplify the ranking between solution attributes. A dominant attribute is one which contains a relatively higher degree of importance than that of another. A distinction is made between the essential and the nonessential phenomena, and the latter are ignored or set aside for a lower level consideration. For example, the performance factor of cost may be an overriding consideration when it is compared to the design factor of color. If it is determined that the factor of color has negligible impact on the factor of cost, then color may be eliminated as a salient solution attribute.

A number of unified analytical methods have been devised for measuring, ranking, and securing solution attributes from problem situations, considerations, specifications, and requirements. (See References 5, 8, 9, 12, 13, and 14.) References 5, 13, and 14 offer the most rigorous and comprehensive techniques for deducing the solution attributes and their subsystem components.

In the preceding discussion, the decision criteria variables (as well as their subsets), dimensionality, dominance, and the ranking of solution attributes were discussed. These ideas are now amalgamated into a concept of utility (value) that can be expressed quantitatively. Fowlkes [ 15] advances the thought that value can be described by a quantitative statement which specifies what is desired, wanted, or needed. (Refer to specification input criteria at Functional Block 3. 0, Fig. 1.) An enumeration of value statements comprises a value system. The value system includes the characteristics of an ideal system and the decision criteria as related to a value model. The ideal system may be characterized by having whatever design elements or operational characteristics that one wishes to incorporate in a scheme. There are very few ideal systems because one usually cannot have everything for which one wishes. The basic function of the value model is to provide a means for developing the relative merits of available alternative solutions. A decision making algorithm (a rule which can be expressed in mathematical terms) can be used to manage the processing and selection of synthesized alternative solutions. A decision algorithm has been devised for such a purpose and will be discussed under the topic entitled, The Selection of a Solution Alternative which Satisfies the Decision Criterion.

A number of authors [ 11, 16, 17, 18] have argued that utility can be thought of in terms of expected loss or gain where all values are forced and registered on a single scale. The concept of utility is welded to how one expresses individual preferences between various alternatives and maintains a consistency in his judgement.

The utility function reflects preferences about the attributes of the alternatives in a given situation, and will reflect not only how one feels about the alternatives (expectation), but how one feels about them in a particular situation. Utility associations are introduced in such a manner as to justify the central role of expected value without further argument. When one prefers alternative A to B, B to C, and A to C, that individual can also assign any three numbers of decreasing magnitude to reflect his ordinal preference. The assignment of quantified numbers to his preference also reflects how that individual feels about his environmental situation. The more certain one either objectively or subjectively feels about selecting a particular alternative over another alternative, one also indicates an assignment of some higher numerical quantity associated with the alternative that gives the greater expected value. Even if one feels uncertain about the selection of his preferences between alternatives, a decision can be made to assign a proportionally higher number to the preferred alternative, and to assign an ordinal value to the statement of uncertainty. In either the case of certainty or uncertainty, it is possible to

state the preference between alternatives in terms of conditional probability. It may be assumed that there is no conceptual difficulty in assigning subjective probabilities to the events in question by using past experience, quantitative data, and the knowledge gained from the experiment. Very little is known about how one assigns subjective probabilities to events, or how they are related to objective probabilities, other than that both types of probabilities are a measure of belief and that mathematically they are identical. Everyone reacts differently to objectives, utility, and expected outcomes. Therefore, the consideration of objectives, assignment of utility values, and the expectation should be evaluated in the light of what these factors mean to the individual who selected them [4, 5, 16, 19]. It is not the intent of this document to explore the concepts of utility and value beyond what has been stated herein. Many excellent text books and lecture notes [5, 11, 16-24] are available and provide an in-depth discussion of the subject matter.

## SYNTHESIZE SOLUTION ALTERNATIVES

The synthesizing of solution alternatives involves the selection of alternative design approaches, identification of acceptable candidate alternatives, and the rejection of unacceptable subsystem approaches. It is important to note that all investigative and assignment efforts (Functional Block 5.0 of Fig. 1) are conducted at the system level. Heretofore, the investigative and assignment tasks were concerned with the solution attributes at the system level. One should also be cognizant of the specifications or performance threshold values that are provided as input data to the decision model at Functional Block 3.0 (Fig. 1). This data flow is now transmitted through the model for further consideration.

The selection of solution alternative design approaches is essentially an investigative survey effort. It should be understood that the salient objective for this effort is to reduce the universal number of promising subsystem design approaches to a number that can be easily managed. Many combinations of physical subsystems can be formulated into a system approach to fulfill specific needs. In turn, each subsystem approach is interrogated to ascertain its related performance levels. As examples of certain end results, one might consider loading characteristics, dimensional configuration and clearances, mechanical or thermal efficiency, friction components, frequency response, optical quality, flow characteristics, etc., which might be contained in the customer's specification requirements. The performance levels are

usually defined as quantitative values from which one may determine the static or dynamic characteristics of the subsystem.

The synthesizing of candidate solution alternatives is a human creative process. The solution attributes that were developed in Functional Block 3.0 (Fig. 1) may now be considered as a set of design criteria by which one may develop candidate solution alternatives. The solution attributes define the needs, but the selection of solution alternatives aims at maximizing the fulfillment of those needs. The candidate solution alternatives usually incorporate many subsystem design approaches. They may combine the best design features from any number of alternative approaches by adapting, modifying, substituting, rearranging, or putting the subsystems to other uses. This effort, if properly accomplished, will result in the establishment of composite candidate solution alternative systems that have the best chance of maximizing the problem solution needs.

In the process of formulating candidate solution alternatives, many subsystem approaches will be evaluated. The design characteristics and performance levels for some subsystem design approaches may not prove as attractive as others. Close scrutiny may show that a given subsystem design approach is either excessively constrained or impractical for application to a higher level. When such a situation is the case, the contending subsystem design approach does not warrant further consideration and may be rejected as an unacceptable approach.

## THE EVALUATION OF THE CANDIDATE SOLUTION ALTERNATIVES

At this point in the design and decision making process, the engineering organization has available both the set of candidate solution alternatives and a set of desired solution attributes along with their associated utility curves, or functions. The function to be performed now is to evaluate the set of candidate solution alternatives with respect to the set of desired solution attributes, and to develop a set of relative utilities to be used later as input data for the decision algorithm. (See Functional Block 6.0, Fig. 1.)

Basically, the evaluation function consists of three distinct steps:  
(1) develop the response of the candidate solution alternatives to the set of desired solution attributes, (2) develop for each candidate solution alternative

a set of utility numbers which are the measures of the particular candidate solution alternative's response to the set of desired solution attributes, and (3) develop for the set of candidate solution alternatives a set of relative utilities for each element in the set of desired solution attributes.

The first step in this evaluation function is the most complicated, and usually represents a major analytical effort. It is during this first step that the alternatives are modeled mathematically so as to predict the candidates' response to the set of desired solution attributes. It is from this mathematical simulation effort that measures of the various parameters are obtained. Further, during this step, a grading of the candidate solution alternatives must be made to obtain response for such nonsimulateable attributes as aesthetic qualities, political implications, etc. The analysis of the parametric criteria is essentially a discovery exercise that not only yields quantitative performance data, but also yields relevant facts and consequences about the solution alternatives. Once the performance values are determined for each candidate solution alternative, they may then be compared to the minimum acceptable threshold performance design criteria. If the response analysis indicates that the solution alternative performance parameters cannot meet the minimum threshold criteria (specifications), then the solution alternative is either rejected or refined until minimum design criteria are satisfied.

With all of the candidate solution alternatives and solution attributes defined, a trade-off analysis is conducted to facilitate the rapid comparison and evaluation of the candidate solution alternatives, and to rank the alternatives so that a consistent course of action is identified with the operational, functional, and technical design requirements and management philosophy. The explicit solution attributes are closely analyzed to ascertain their relative importance to the solution alternatives. This function requires the estimation and assignment of relative utility between the solution alternatives. The assignment of utility values represents a measure of solution alternative goodness. The trade-off analysis, as outlined in Reference 25, assures that only reasonably acceptable solution alternatives are presented for final consideration.

The second step consists of taking the values obtained during the response analysis for each candidate alternative and by referring to the utility curves for each desired solution attribute, determining the set of utility numbers for each candidate.

The third step consists of taking the sets of utility numbers and calculating sets of relative utilities  $(R_{u_i}^k)$  for each desired solution attribute.

These relative utilities are calculated by means of the following equation:

$$R_{u_i j}^k = \frac{U_i^k}{U_i^k + U_j^k},$$

where

$U_i^k$  = utility number for candidate solution alternative  $i$  for desired solution attribute  $k$

and

$U_j^k$  = utility number for candidate solution alternative  $j$  for desired solution attribute  $k$ .

When the utility curves could not be developed for the set of desired solution attributes, the values for the relative utilities must necessarily be estimated by means of expert judgment. The only restriction on their value is that

$$R_{u_i j}^k + R_{u_j i}^k = 1,$$

and

$$0 \leq R_{u_i j}^k \quad \text{and} \quad R_{u_j i}^k \leq 1$$

One of the main reasons for using relative utilities as inputs to the decision algorithm, as opposed to the actual utility curves and the values for the response parameters, is the greatly increased flexibility of program usage. In actual practice, utility curves are sometimes difficult to obtain; whereas, in their absence, the relative utilities often can be estimated fairly easily and with a reasonable degree of confidence.

## ANALYZE ALTERNATIVE SOLUTIONS FOR ADVERSE CONSEQUENCES

Having developed more than one candidate solution that promises to meet the required specifications, one additional analytical phase is necessary prior to submitting the candidate solutions to the value model decision algorithm. (See Functional Block 7.0, Fig. 1.) The purpose of this phase is to critically examine the candidate solutions from the risk point-of-view. That is, each candidate solution must be examined to determine the level of risk involved with its selection and to determine the compatibility of this risk with the corporation's and customer's philosophy.

The first part of this analysis is concerned with isolating those portions of each solution and ascertaining the level of risk associated with it. It is necessary to examine the states of nature and determine the consequences should the adverse aspects of the risks occur. It is necessary to determine the probability of the occurrence of the adverse aspects. From the consequences and probabilities, a probable loss value can be calculated. This is in essence an expected negative utility.

The second portion of this analysis is concerned with determining the compatibility of the probable loss with the corporate's and/or customer's philosophy. If for any of the proposed solutions, this probable loss figure is unacceptable, that alternative is either rejected, or a requirement is imposed at Functional Block 5.0 (Fig. 1) to improve those high risk aspects associated with the alternative.

If none of the proposed solutions are compatible with the corporate's or customer's risk philosophy and if subsystem reevaluation cannot correct the situation, then it is necessary to iterate the solutions back to Functional Block 2.0 (Fig. 1) where the program objectives were first formulated. It could, of course be decided that within the imposed constraints and with the current state-of-the-art, no acceptable solution can be formulated.

If a set of alternatives are deemed both technically sound and risk-wise feasible, then the data for the alternatives are submitted to the decision algorithm. There the expected utility is calculated for each alternative, and the alternative with the largest expected utility is the rational choice.

## THE SELECTION OF A SOLUTION ALTERNATIVE THAT SATISFIES THE DECISION CRITERION

A decision making algorithm has been devised that makes use of a utility/probability approach and also allows for the consideration of the uncertainty of a decision. The algorithm is used to select a solution alternative that satisfies the decision criterion. (See Functional Block 8.0, Fig. 1.) The decision algorithm described in this report is a refinement of the technique of "forced decisions" as presented by Fasal [26]. The technique described therein is essentially a weighting factor or ranking selection method used to determine the relative value of design characteristics between products. The author used a deterministic approach for forcing a decision of expected value, with no consideration given to the uncertainty of his decision. The author was absolute in his decision making processes.

The decision algorithm presented herein consists of four parts. The first and second parts are concerned with the determination of the relative importance of each of the solution attributes (these may be objectives, component variables, design criteria, specifications, cost limitations, functional and operational requirements, etc.) and the checking of these data for consistency. The relative importance of each of these attributes is determined by considering the attributes pairwise. This direct comparison of the utilities associated with two attributes provides a basis for stating that one solution attribute (in our problem situation: "objectives") is more important than another. The mapping of the utility information (value) into the closed interval  $[0, 1]$ , in conjunction with equation (10), is the means by which the relative importance data for the decision algorithm is generated. This mapping process varies according to the manner in which the attribute utilities are represented. Common to all such mapping processes is that the relative importance between the solution attributes is established. The relative importance between the solution attributes is an equivalence relation on the cartesian product of the set of solution attributes with itself. This means that the relative importance between attributes induces a partial ordering upon the set of solution attributes. One property of an equivalence relation is that the relation is transitive. A transitive relation is one such that if  $X$  is related to  $Y$ , and if  $Y$  is related to  $Z$ , then  $X$  is also related to  $Z$ . This property makes it possible to check the consistency of the data for the solution attributes importance scores by means of a simple test. Consider three solution attributes  $X$ ,  $Y$ , and  $Z$ , and denote by  $X \rightarrow Y$  that attribute  $X$  is more important than  $Y$ . By consistency, it is meant that if  $X \rightarrow Y$  and  $Y \rightarrow Z$ , then  $X \rightarrow Z$  also. An inconsistency would be of the form  $X \rightarrow Y$ ,  $Y \rightarrow Z$ , and  $Z \rightarrow X$ . Clearly,

as related in References 5, 11, 20, an inconsistency is not transitive and therefore it will not induce a partial ordering upon the set of solution attributes.

The algorithm assumes that the input data is consistent, and it will rank the systems even if the data is inconsistent. However, a ranking based upon inconsistent data can be completely devoid of meaning. Consequently, the input data should be checked for consistency prior to using the decision algorithm. This can be easily accomplished by subjecting the data to the logical test as stated below.

Let  $(\text{SPEM})$  be the matrix of solution attribute importance scores; then, the satisfaction of the logical statement:

$$\begin{aligned} & [(\text{SPEM}_{ij} \geq \text{SPEM}_{ji} \geq \dots \text{AND} \text{SPEM}_{jk} \geq \text{SPEM}_{kj} \geq \dots \text{AND} \text{SPEM}_{ki} \geq \text{SPEM}_{ik}) \\ & \text{. OR. } (\text{SPEM}_{ij} \leq \text{SPEM}_{ji} \text{. AND. } \text{SPEM}_{jk} \leq \text{SPEM}_{kj} \text{. AND. } \text{SPEM}_{ki} \leq \text{SPEM}_{ik})] \\ & = \text{TRUE} \end{aligned} \quad (1)$$

is the criterion for data consistency. There are a specific maximum number of inconsistencies possible for a given set of data. If  $n$  is the number of solution attributes, then the maximum number of inconsistencies ( $I_m$ ), is given by:

$$I_m = (n^3 - n)/24 \quad \text{if } n \text{ is odd,} \quad (2)$$

and

$$I_m = (n^3 - 4n)/24 \quad \text{if } n \text{ is even.} \quad (3)$$

When it is necessary to rank the systems using inconsistent data, it is useful to have some measure of data consistency so as to better evaluate the results. Such a measure is called the coefficient of consistency ( $K$ ) and is calculated from

$$K = 1 - I_o/I_m \quad (4)$$

where  $I_o$  is the observed number of inconsistencies. When  $K = 1$ , the data are completely consistent, and when  $K = 0$ , the data contain the maximum number of inconsistencies possible for the solution attributes considered. Moroney presents a comprehensive explanation of the handling of inconsistencies as found in Reference 27. Once the positive decision scores have been checked for consistency, an emphasis (importance) coefficient is calculated according to the scheme described later on in this section. The solution attribute with the largest emphasis coefficient is considered to be the most important. To illustrate this last thought, consider the system design characteristics given in the SAL problem situation (Appendix A). Fourteen design characteristics are listed in Table C-1 (Appendix C). These characteristics represent solution attributes (an amalgamation of decision criterion variables, component variables, sub-objectives, facts, opinions, etc.) which influence the assignment of a utility/probability value to a given attribute. Before a utility/probability value can be assigned to a set of solution attributes, the investigator must analyze each solution attribute separately to establish its relative intrinsic value to the investigator. If a given attribute has no intrinsic value to the investigator, then the integer 0 may be assigned to the upper portion of the cell. (The lower portion of the cell is concerned with the estimate of uncertainty associated with the ranking choice.) If the attribute has maximum intrinsic value, then the integer 1.0 may be assigned. If the investigator wishes to denote a "no choice" between the utility value limits, then the integer 0.5 may be assigned. A summation of the partial values for a given attribute yields the absolute utility value for that same attribute.

The third part consists of a system comparison analysis in which the competitive systems are ranked according to how they satisfy each individual solution attribute. Once again, sets of emphasis coefficients are calculated to represent quantitatively the ranking results. An example of how the systems comparison analysis is conducted is found in Appendix C, Table C-4.

The fourth part consists of calculating the merit scores and uncertainties for each score for each of the competitive solution alternatives. These scores are all normalized to unity, and the solution alternative that has the largest numerical score is the alternative that best satisfies the total set of solution attributes. The uncertainty associated with each score is a measure of possible numerical error in the computed score. (See example in Appendix C, Table C-6.) When use of the algorithm yields nearly equal scores for two or more of the competitive alternatives, this is an indication that there is virtually no significant difference in the ability of the two solution alternatives to satisfy the specified criteria. However, when the score of one system is substantially

larger than the score for the others, this is an indication that the alternative with the larger score excels over the other candidate solution alternatives in satisfying the overall system requirements. From the difference of the scores for two competitive systems and the uncertainties, a factor can be calculated that is a measure of the confidence that the two systems actually rank according to their merit scores.

The mathematical formalization of the decision algorithm has been organized to facilitate the programming of the method for a digital computer, and to minimize the number of data items required to initialize a given problem. The decision algorithm consists of four parts: (1) checking of the decision data for consistency; (2) computation of the solution attribute emphasis coefficients; (3) computation of the solution comparison emphasis coefficients; and (4) computation of the merit scores.

Assume that the positive decision scores for the solution attributes have been arranged in two  $n \times n$  matrixes  $(SPEM)^*$  and  $(a)$ . The  $(SPEM)^*$  statement contains the decisions, and  $(a)$  contains the uncertainties associated with each of the decisions. The sum of these two matrixes will be referred to as the solution properties matrix and will be denoted by  $(SPEM)$ . Thus

$$(SPEM) = (SPEM)^* + (a) \quad (5)$$

The  $(ij)$  element of  $(SPEM)^*$  is the relative importance score of the  $i$ th property compared to the  $j$ th property. The relative importance of one solution attribute with itself is of no interest, and consequently, the diagonal elements of  $(SPEM)^*$  and  $(a)$  are equal to zero. The decision scores and the associated uncertainties for a given attribute pair shall be restricted so that the sum of the scores and the uncertainties shall be equal to one (i.e.,  $\text{score}_{ij} + \text{uncertainty}_{ij} + \text{score}_{ji} + \text{uncertainty}_{ji} = 1$ ). This restriction will cause all of the computed coefficients and merit coefficients to lie in the closed interval  $[0, 1]$ . This restriction, along with the assumption that the total uncertainty associated with a given pair split proportionally between the two attributes, makes it possible to minimize the number of required problem initialization data items. The problem initialization data items for the first part of the decision algorithm consist of the upper triangular parts of  $(SPEM)^*$  and  $(a_T)$  where  $(a_T)$  is an  $n \times n$  matrix containing the total uncertainties associated with a given pair score. Further,  $(a_T)$  satisfies the relation

$$(a_T)_{ij} = (a)_{ij} + (a)_{ji} \quad (6)$$

Since the uncertainties are split proportionally between the two scores for a given attribute pair, it follows that

$$(a)_{ij} = \frac{(\text{SPEM})^*_{ij}}{(\text{SPEM})^*_{ji}} \quad (a)_{ji} \quad (7)$$

Solving equations (6) and (7) simultaneously yields

$$(a)_{ij} = \frac{(\text{SPEM})^*_{ij}}{1 - (a_T)_{ij}} \quad (a_T)_{ij} \quad (8)$$

and

$$(a)_{ji} = \frac{(\text{SPEM})^*_{ji}}{1 - (a_T)_{ij}} \quad (a_T)_{ij} \quad (9)$$

Since the importance scores and uncertainties for a given pair sum to one, it follows that

$$(\text{SPEM})^*_{ji} = 1 - (\text{SPEM})^*_{ij} - (a_T)_{ij} \quad (10)$$

Consequently, all elements of both  $(\text{SPEM})^*$  and  $(a)$  may be calculated given the upper triangular portion of  $(\text{SPEM})^*$  and  $(a_T)$ .

The emphasis coefficient associated with each solution attribute is defined as the sum of the importance scores for that attribute normalized by the total number of pairwise comparisons made. The complete solution attribute emphasis coefficient vector (SPEC) can be calculated from the matrix equation

$$(\text{SPEC}) = \frac{2}{n(n-1)} (\text{SPEM}) (\text{S})^T ,$$

where  $(\text{S})$  is the row vector

$$(\text{S}) = (1 \ 1 \ 1 \ \dots \ 1) \quad \overbrace{\quad \quad \quad}^n$$

The explicit computational formula is

$$\begin{aligned} (\text{SPEC})_i &= \frac{2}{n(n-1)} \sum_{k=1}^n (\text{SPEM})_{ik}^* + \frac{2}{n(n-1)} \sum_{k=1}^n (\text{a})_{ik} \\ &= (\text{SPEC})_i^* + (\text{a})_i, \quad i = 1, 2, \dots, n \end{aligned} \quad (11)$$

The first term on the right is the solution attribute emphasis coefficient for the  $i$ th attribute. Assume that there are  $p$  systems to be compared. The data will be arranged in two three-dimensional  $p \times p \times n$  matrixes  $(\text{SCEM})^*$  and  $(\text{b})$ . As before, the initialization data will consist of only the upper triangular part of  $(\text{SCEM})^*$  and  $(\text{b}_T)$ , where  $(\text{b}_T)$  satisfies the relation

$$(\text{b}_T)_{ijk} = (\text{b})_{ijk} + (\text{b})_{jik} \quad (12)$$

Further, the uncertainties are assumed to be split proportionally. Consequently, it follows that

$$(\text{b})_{ijk} = \frac{(\text{SCEM})_{ijk}^*}{1 - (\text{b}_T)_{ijk}} \quad (\text{b}_T)_{ijk} \quad (13)$$

and

$$(b)_{jik} = \frac{(SCEM)^*_{jik}}{1 - (b_T)_{ijk}} \quad (b_T)_{ijk} \quad (14)$$

The matrix of complete system comparison emphasis coefficients (SCEC) can be computed from the equation

$$(SCEC) = \frac{2}{p(p-1)} (SCEM)(S) = \frac{2}{p(p-1)} (SCEM)^*(S) + (b)(S) .$$

The explicit computational form is

$$(SCEC)_{ik} = \frac{2}{p(p-1)} \sum_{j=1}^n (SCEM)^*_{ijk} + \frac{2}{p(p-1)} \sum_{j=1}^n (b)_{ijk} ,$$

$$= (SCEC)^*_{ik} + (B)_{ik} \quad (15)$$

where  $i = 1, 2, \dots, p$  and  $k = 1, 2, \dots, n$ . The first term on the right is the system comparison emphasis coefficient for the  $i$ th system and the  $k$ th attribute, and the second term is the associated uncertainty.

The system's merit coefficient is the combined emphasis coefficient which is a relative measure of how well a given system satisfies the solution alternatives. The vector of complete solution alternative merit coefficients (SMV) is computed as follows:

$$(SMV) = (SCEC)(SPEC)$$

$$= [(SCEC)^* + (B)] [(SPEC)^* + (A)]$$

$$= (SCEC)^*(SPEC)^* + (SCEC)^*(A) + (B)(SPEC)^* + (B)(A)$$

$$= (SMV)^* + (E) .$$

The first term on the right is the desired vector alternative merit coefficients, and the second term is the vector of associated uncertainties. The explicit computational forms are:

$$(\text{SMV})_i^* = \sum_{k=1}^n (\text{SCEC})_{ik}^* (\text{SPEC})_k^* , \quad (16)$$

where  $i = 1, 2, \dots, p$  ,

and

$$(\text{E})_i = \sum_{k=1}^n (\text{SPEC})_{ik}^* (\text{A})_k + (\text{B})_{ik} (\text{SPEC})_k^* + (\text{B})_{ik} (\text{A})_k . \quad (17)$$

When comparing two candidate solution alternatives with nearly equal scores, scrutiny must be given to the associated uncertainties, error (E). In particular, when comparing alternative  $x$  with alternative  $y$  , either

$$(\text{SMV})_x - (\text{E})_x > (\text{SMV})_y + (\text{E})_y \quad (18)$$

or

$$(\text{SMV})_x + (\text{E})_x < (\text{SMV})_y - (\text{E})_y \quad (19)$$

must hold true before a rational choice can be made between the two solution alternatives.

In actual practice, it has occurred that the calculated emphasis coefficients do not quite represent the true opinion nor philosophy of the decision maker. What occurs is that the most important items receive a disproportionate emphasis relative to the least important items. The ordering of the items are correct for the most part as well as are the actual values of the emphasis coefficients. However, it is desirable to introduce a method to scale these coefficients so as to better represent the decision maker's true opinion.

This scaling can be accomplished by using a form of Steven's Law [28] to map the set of emphasis coefficients onto a set of modified emphasis coefficients. The relative magnitude of the modified coefficients will better represent the decision maker's opinions. This mapping process can be accomplished by means of the equation:

$$E_c^m = E_{c_{\max}} \left( \frac{E_c}{E_{c_{\max}}} \right)^s, \quad (20)$$

where

$E_c^m$  = modified emphasis coefficient

$E_c$  = emphasis coefficient

$E_{c_{\max}}$  = maximum value contained in the set of emphasis coefficients

and

$s$  = scaling exponent

The effect of applying this formula is shown in Figure 2.

As can be seen from this figure, when  $s = 1$ , the modified emphasis coefficients are numerically equal to the emphasis coefficients. When  $s > 1$ , the differences between the various values are emphasized. When  $s < 1$ , the differences between the various values are de-emphasized. Experience has shown that the differences need a slight amount of emphasizing. Consequently, a value of  $s$  should be chosen such that  $s > 1$ . Experiments are presently being conducted to determine the appropriate values for this constant.

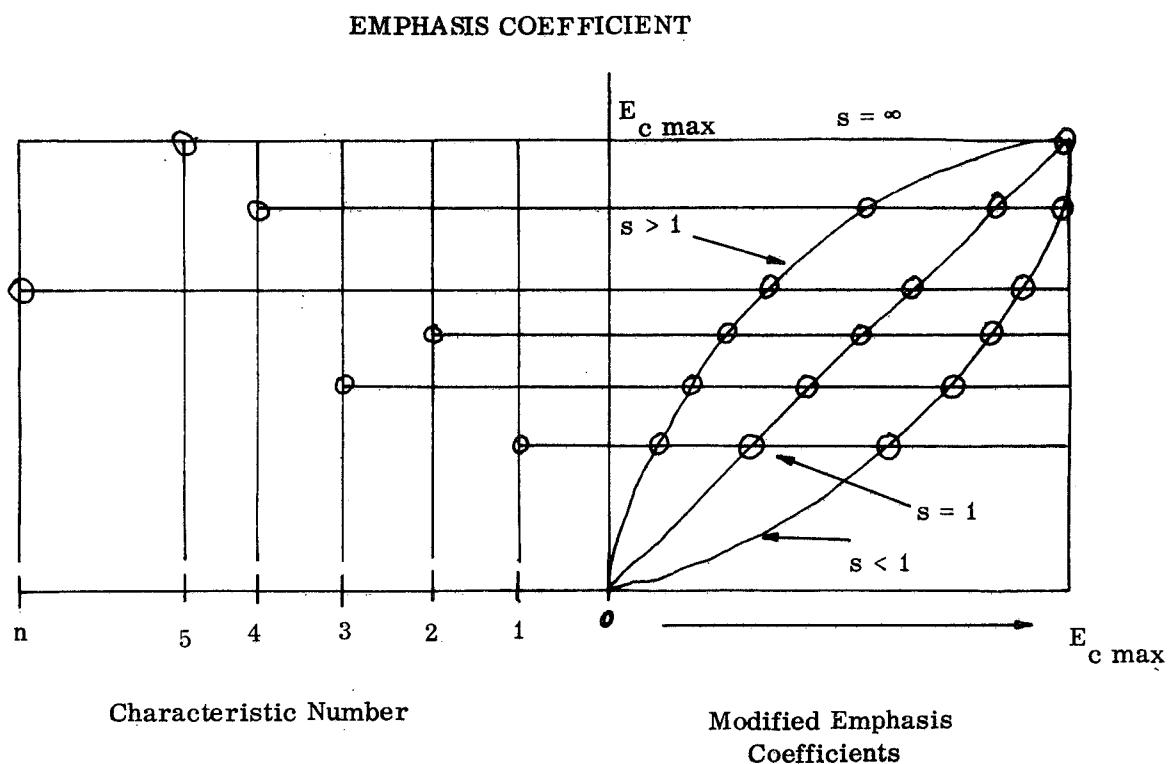


Figure 2. Steven's Law scaling curves.

## APPENDIX A SAL DECISION PROBLEM

### ASSIGNMENT OF THE SAL DECISION PROBLEM

It was directed by Systems Coordination Section (S&E-ASTN-VAC) that Brown Engineering Company, Systems Integration Section (BSVD-V2I) investigate the selection of an appropriate location for installing the SAL on the AAP-2 Orbital Assembly. This problem was referred to the Engineering Analysis Section (BSVD-V2E) for the purpose of devising an orderly and timely systems engineering decision making method in which the above problem, and others of a decision making nature, could be resolved.

### ASSUMPTIONS

1. If the engineering modification is to be performed on the MDA and the SAL is to be installed on the same structure, then MSFC will accomplish the tasks.
2. The MDA docking window is assumed to be located at MSFC Station 2037.569. Assume the docking window to be 8.0 inches wide by 12.0 inches long.
3. Assume the MDA docking panel control station to be located at MSFC Station 2011.569.
4. Structural Transition Section window cutouts are provided in the radiator structural cover skin.
5. If the SAL is to be located on the AM/STS, then an aerospace contractor will probably be selected to accomplish the modification and installation tasks. Also assume that there is a chance that MSFC might designate an aerospace contractor to accomplish the SAL modification and installation tasks on the MDA.
6. Assume the glide-slope indicator to be located on the MDA/LM docking panel within the MDA.

7. Assume AAP experiments T-017 and T-021 to be located on the AM/STS between MSFC Station 1850.560 and 1807.569. Assume the experiment structural framework and panels to extend 96.0 inches outboard the STS/MDA.
8. Assume AAP experiment T-027 (ATM Contamination Measurement) must be operated through the SAL and extend outboard the orbital assembly towards the LM/ATM.
9. Assume AAP experiment T-025 (Coronagraph Contamination Measurement) must be operated through the SAL and extend outboard the orbital assembly to measure sunlight, solar illumination, and atmospheric reflection.
10. Assume AAP experiment S-018 (Micrometeoroid Collection) must be operated through the SAL and extend outboard the orbital assembly to collect small micrometeoroids, measure meteoroid flux, and collect bio-specimens.
11. Determine which solution alternative is the most expensive by using cost analysis, and assume this approach to be the normalized case.

## DESCRIPTION OF THE DECISION SITUATION

In deference to the particular problem situation discussed herein, it is found that many technical and management considerations affect the final problem definition. Tables A-1 and A-2 summarize a number of such considerations. These considerations identify general and specific design requirements, philosophical position, relative environment, boundary conditions (all established through research techniques), and contribute to the description of the decision situation. A description of the decision situation for this study may be characterized by the desire of MSFC to select a method for locating a SAL on the AAP-2 Orbital Assembly (OA) so that established experiment and mission goals can be fulfilled. The most likely location to place the SAL is on either the MDA or AM/STS subassemblies. There also exists the possibility of locating the SAL at one of four locations, two on the MDA and two on the STS (Fig. A-1). The four choices outlined above suggest that the decision maker will be faced with the optimization of a SAL location as well as the choice of how the selection of alternatives are to be implemented. Finally, the problem situation is such that not all of the input information (design considerations, requirements,

TABLE A-1. SAL PROBLEM SITUATION DESCRIPTION — TECHNICAL CONSIDERATIONS

Number	Technical Considerations
1.	How much MDA or STS wall area will be consumed after installing the SAL?
2.	How much launch storage area is available over the SAL after installation?
3.	What type of structural interface and handling problems are to be anticipated?
4.	What type of structural elements are expected to be modified in the MDA or STS?
5.	What internal components (experiment packages, handrails, operational flight support equipment, hardware, etc.) are expected to be relocated because of the impact of positioning the SAL?
6.	Would it be easier and less costly to reference and locate the SAL on or off the MDA/STS vertical (X) structural axis system?
7.	Can AAP experiments S-018, T-025, and T-027 be operated through the SAL once its location is determined?
8.	What other AAP experiments are serviced by the SAL?
9.	Will there be adequate clearance to operate the AAP experiment extension and push rods through the SAL from within the MDA or STS work areas? Will there be adequate clearance to operate the above rods through the SAL outboard, the MDA, or STS? Will there be interference with the LM or ATM structure?
10.	Will there be adequate astronaut crewmember working clearance and maneuverability in the MDA or STS once the SAL is installed?
11.	Does the MDA/STS radiator require major or minor modification?
12.	Will the SAL be susceptible to micrometeoroid impact damage, or contamination because of outgassing of equipment or experiments?
13.	Will the location of the SAL be positioned near the MDA control station so that the glide-slope indicator may be referred to during AAP experiment operations?

TABLE A-1 (Concluded)

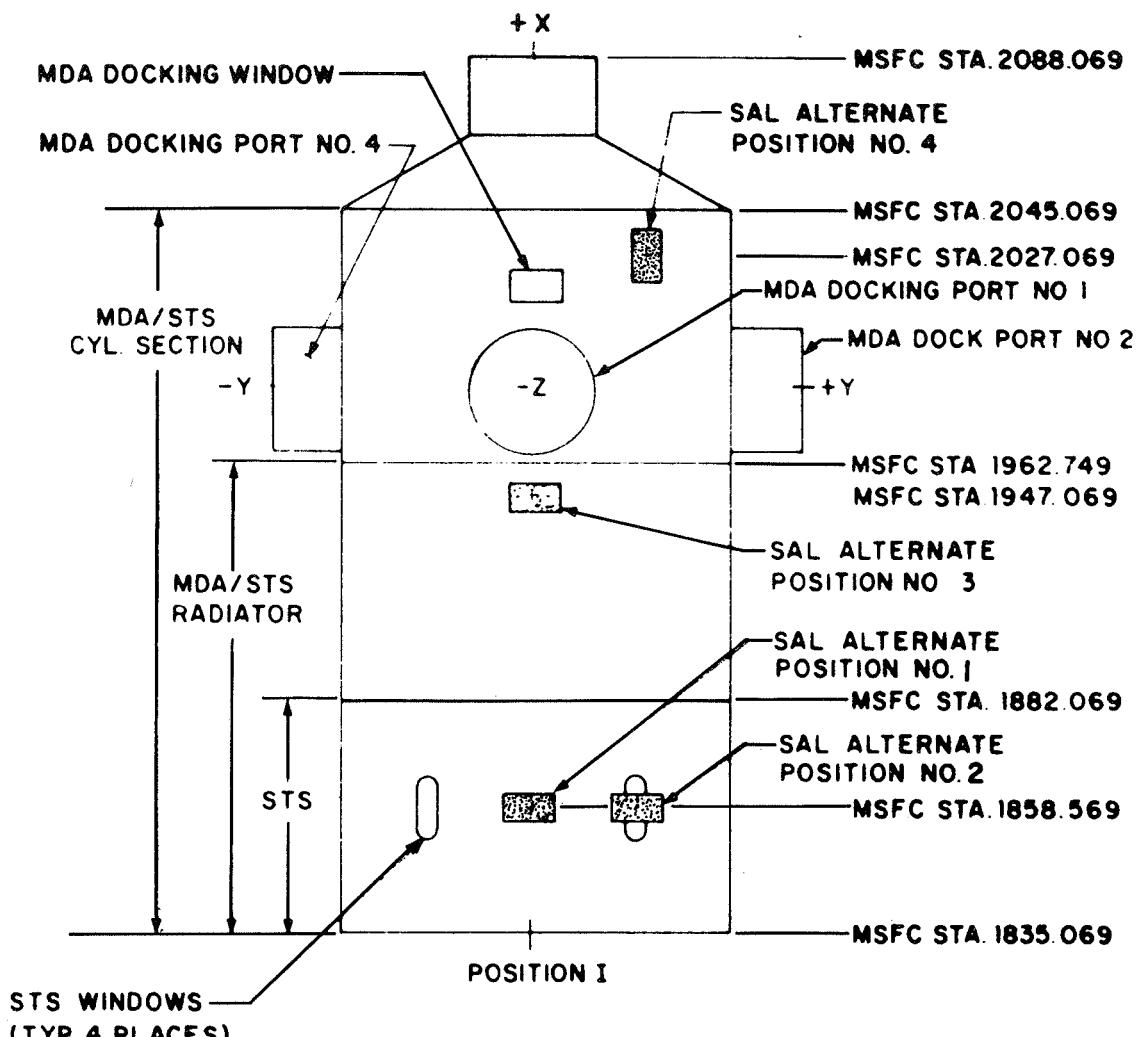
Number	Technical Considerations
14.	Can the T-027 experiment photometer canister interface to the SAL?
15.	Is the optimum location of the SAL the best position to support the AAP-3 and 4 missions?
16.	Who will operate the SAL during flight operations? How many personnel will work in the immediate area during SAL experiment operation?
17.	How do AAP experiments T-017 and T-021 affect the SAL operation or support requirements?
18.	What relative importance does the Astronautics Laboratory attach to SAL size, operational convenience and safety, choice of location and orientation position, and relocation of internal MDA/STS equipment?
19.	Does Human Factors Engineering have a preference for locating the SAL on the MDA/STS module?
20.	Are there critical distances that must be maintained between the SAL and other structural assemblies or components (Orbital Workshop, LM/ATM, and CSM)?
21.	If technical (specifications) and operational SAL standards exist, are these consonant with the values of required system variables, or must those standards be modified to meet new system values?
22.	Is it considered a major or minor modification when mounting the SAL to the MDA or STS?

TABLE A-2. SAL PROBLEM SITUATION DESCRIPTION — MANAGEMENT CONSIDERATIONS

Number	Management Considerations
1.	Does NASA have any outstanding contractual obligations or previous management agreements with outside aerospace contractors that could dictate or materially influence the outcome of structural modification, SAL installation, and facility support costs?
2.	What resources (labor, material, facility support, capital, and time) are available for modifying the MDA or AM/STS, relocating internal equipment, and installing the SAL in an optimum location? Can it be assumed that all resources are minimized while the technical gains (value) are to be maximized? Does the minimization of resources, and maximization of value represent a valid decision criterion?
3.	What engineering solution attributes must be considered for the selection of an optimum SAL location?
4.	Who will perform the actual modification, installation, and support effort, and in what facility will this effort be accomplished? If the modification is to be accomplished and the SAL installed on the MDA, then can it be assumed that MSFC will perform the above tasks? Or rather, can it be assumed that an aerospace contractor will accomplish the modification and installation tasks if they are performed on the AM/STS module?
5.	Will interfacility or intralaboratory heavy duty transportation equipment be available to move the MDA and STS? Will transportation and storage costs materially impact management's decision to do the job at MSFC or subcontract the job to an aerospace manufacturer?
6.	How much time is required to complete the overall modifications and SAL installation? How much time is required for structural integrity testing?
7.	Will the structural modification, SAL installation, and testing effort be completed in time to support the AAP-2 mission? How about the AAP-3 and 4 missions?
8.	What are the AAP experiment mission requirements for the SAL?

TABLE A-2 (Concluded)

Number	Management Considerations
9.	How much cost savings can NASA realize if MSFC performs the modification of the structure, installation of the SAL, and testing of the system?
10.	Can the functional objectives be stated quantitatively (assigned value of utility) and ranked (assigned an order of importance) with a high degree of confidence?
11.	Can NASA make use of the MSFC facilities and existing manpower to modify the MDA or STS structure, install the SAL, and test for integrity, or would it be cheaper and quicker to perform the above tasks at an aerospace contractor's facility?



Note: MDA docking ports 2 and 3 may be removed at a later date.

Figure A-1. Multiple Docking Adapter and Structural Transition Section configuration

specifications, etc.) are completely known, or can be fully relied upon for any length of time. Consequently, this is an example of decision making under the condition of uncertainty.

Normally, the customer (MSFC) would outline or detail the desired design specifications, experiment requirements, anticipated performance, threshold values, etc., but the nature of the SAL problem situation did not avail itself to such an unequivocal approach. Several levels of intralaboratory

and interlaboratory communication problems arose (as well as communication of proprietary contractual data between a private aerospace contractor, support contractor, and MSFC) that prohibited MSFC from defining the SAL design requirements and anticipated performance threshold values. This problem was deferred until a list of solution attributes could be developed and an estimate of design performance could be assumed.

## STATE THE PRIMARY OBJECTIVES

From the description of the SAL related decision situation, a primary objective may be succinctly stated:

Determine the optimal location and installation for the SAL on either the MDA or AM/STS maximizing the expected engineering and operational value, while minimizing overall modification time and cost. The SAL shall support the AAP-2 through 4 mission experiment requirements as deemed necessary.

The general goal is to fulfill the customer's (MSFC) needs, but the particular goal is to select an optimal location for the SAL and install such on the MDA or AM/STS. There are two courses of action to choose from, as implied by the statements of maximization and minimization. For this problem situation, one course of action will be that MSFC chooses to accomplish the primary objective, or that MSFC will delegate this responsibility to an aerospace contractor (the second course of action).

## DEVELOP A LIST OF SOLUTION ATTRIBUTES

Pursuant to the particular problem situation, we are concerned with the selection of solution attributes at the subsystem level that define alternative value systems and alternate physical systems. The solution attributes should be explicit and define goodness in terms of effectiveness, expenditure of resources, and time. The solution attributes selected for this study are the results of a distillation of technical and management considerations that primarily annotate the value of an end system. The numerical values stated below are the results of assumptions, considered opinions, and mathematical analyses that were developed in Appendix A (Tables A-3 and A-4) and

TABLE A-3. SAL SOLUTION ATTRIBUTE COMPONENT SUMMARY SHEET

Solution Attributes	1 Dimension of Solution Attribute Variables	2 Solution Attribute Value Range	3 Average Solution Attribute Value Range (Threshold Values)	4 Emphasis Coefficient (See Table C-3)
Modification of the Structure	Cost (\$)	172 680.00 - 327 600.00	250 140.00	0.08461
Radiator Modification	Cost (\$)	0.00 - 163 800.00	81 900.00	0.06703
Relocation of Internal Equipment	Cost (\$)	30 712.50 - 282 555.00	156 633.75	0.07142
Launch Storage Area	Area (in. <sup>2</sup> )	0.0 - 196.0	98.0	0.02857
Wall Area Consumed by SAL	Area (in. <sup>2</sup> )	315.0 - 325.0	320.0	0.03076
Reflection, Outgassing from T-017, T-021 Experiments	Line-of-Sight Distance (in.)	96.75 - 217.00	156.875	0.06483
Crew Obstructions	Protrusion Distance (in.)	40 - 64	52	0.05824
Near Control Station	Line-of-Sight Distance (in.)	46.25 - 159.25	102.75	0.04615
SAL Extension Rod Clearance	Distance (in.)	24 - 36	30	0.06263
Transportation	Cost (\$)	2 047.50 - 81 900.00	41 973.87	0.05054
Schedule Effect - SAL Installation	Time (days)	20 - 45	32.5	0.05274
Schedule - AAP-2-Mission	Time (months)	2.5 - 4.0	3.25	0.07252
Use During AAP-3/AAP-4 Mission	Time (months) Distance (in.)	4 - 8 96 - 121	6 108.5	0.09450
NASA Contractual Obligations and Cost	Cost (\$) Philosophy (Intangible)	208 770.00 - 819 000.00 —	513 885.00 —	0.12747

Appendix B. The following solution attributes are considered relevant to the problem situation:

1. Assuming that a normalized cost of modifying either the MDA or STS modules can be established at 32.76 percent of the total modification cost (in support of the SAL installation requirement), determine the minimum net cost and specify an optimized configuration. Physical handling, manufacture processing, and rerouting of system carrier lines must be minimized.
2. Assuming that a normalized cost of modifying the MDA/STS radiator can be established at 16.38 percent of the total modification cost (in support of the SAL installation requirement), determine the minimum net cost and specify an optimized configuration. Structural modification, rerouting of cooling lines, and addition of standoff hardware must be minimized.
3. Assuming that a normalized cost of relocating the internal MDA or STS equipment (storage packages, experiments, handrails and mobility aids, flight equipment, etc.) can be established at 24.57 percent of the total modification cost (in support of the SAL installation requirement), determine the minimum net cost, and specify an optimized configuration. The relocation of primary flight support systems and hardware must be minimized.
4. To ensure the operational success, safety, and protection of those AAP experiments operating through the SAL, the reflection of micrometeoroid particles (including abrasive exhaust gas particles from the RCS rockets) and outgassing from flight hardware must be minimized. The location of the SAL must not interfere with the operation of AAP experiments T-017 and T-021.
5. To ensure ease of flight reference position during AAP experiment operations, it is highly desirable that the SAL be located near the glide-slope indicator on the MDA control station panel, or near the MDA control station.
6. To ensure the operational success of those AAP experiments operated through the SAL with mechanical extension or manual push rods, adequate MDA or STS internal operational handling

space must be provided for the crew member to assemble the rods. The determination of the SAL extension rod clearance requirements is essential. The relocation of internal MDA or STS hardware must be minimized.

7. It is necessary to interface the T-027 experiment photometric extension rod canister to the SAL during experiment operations. Determine the astronauts' relative working and maneuverability clearance within the MDA or STS modules when the photometric extension rod canister is installed on the SAL. Select a SAL installation configuration that best meets the above requirements.
8. It is highly desirable that a minimum of MDA or STS interior wall surface area be consumed when installing the SAL. Identify an optimized SAL installation considering consumed wall area and best installation position.
9. It is desirable that the SAL be installed in either the MDA or STS module to ensure maximum storage area directly over the SAL. Select an optimized location to ensure adequate astronaut SAL work station clearance and maximum storage area capacity.
10. Assuming that a normalized cost of transporting the MDA, STS, or MDA/STS modules can be established at 8.19 percent of the total modification cost (in support of the SAL installation requirement), determine the minimum net cost and specify which module or combination of modules would be easiest and cheapest to transport. Handling must be minimized.
11. To ensure a reasonable project modification time schedule for accomplishing all manufacturing, SAL installation, and equipment relocation tasks, estimate the required working days to complete the above tasks. It is imperative that the working days be kept to a minimum to avoid excessive stretching out of AAP mission launch schedules.
12. A reasonable AAP-2 project modification time schedule for accomplishing all modification work, installations, reassemblies, testing, qualifications, and support tasks must be estimated. It is imperative that the time to accomplish these tasks be kept to a minimum to avoid AAP-2 mission schedule impacting.

13. For the SAL to support the AAP-3 and 4 missions experiment operational requirements, the unit installation must not physically interfere with experiments T-017 and T-021. Experiments S-018, T-025, and T-027 must be operated through the SAL, free from human or mechanical impairment or interference from surrounding OA structure. The selection of a SAL position must be critically evaluated in terms of cost, mission consequences, and the likelihood of NASA to select the optimized configuration.
14. Assuming that the total cost of modifying the MDA or STS modules, installing the SAL, relocating internal equipment, and provision of support services can be normalized and established at \$1,000,000, select an optimized configuration that minimizes the total modification expense. A profit or cost saving of 18.10 percent may be realized, depending on whether an aerospace contractor or MSFC accomplishes the modification effort. Any outstanding contractual obligations affecting the total modification effort between NASA and an aerospace contractor should be so noted.

## RANK SOLUTION ATTRIBUTES AND OBTAIN UTILITY CURVE

The decision criteria are usually defined in terms of subsystem solution attributes that have some expected value associated with the attribute. Each attribute has a particular measure of value that, in most cases, must be related to a multidimensional scale to ensure consistency of evaluation and comparison. Further, a relative weighting value is assigned to each attribute which aids in the ordering of all relevant solution attributes. This ordering implies that some attributes are more important than others and therefore should carry greater emphasis. Table A-3 summarizes and correlates the relevant solution attributes, dimensional scales, value ranges, threshold values, and sensitivity data associated with the SAL decision situation. An inspection of the emphasis coefficient column on Table A-3 shows that the NASA Contractual Obligation and Cost criteria are far more important than the Launch Storage Area criteria. It may be stated that the preceding criteria play a dominant role over the latter criteria, and relegates the latter criteria to such a minor level of importance that it has little influence in the decision making process when these two attributes are compared. The Launch Storage

Area criteria were not eliminated from the decision making process because they play an important evaluation role with respect to other design and operational criteria, but at a much lower level of consideration.

The nature of the SAL problem situation suggests that the decisions be classified according to a choice between ends (alternate value system) rather than means (alternate physical system); that is, to investigate the conditional statement of "Alternative A is preferred over Alternative B" because of its greater value. The ends, however, cannot be chosen independently of the means. The ends are classified according to their relation in a piece of reasoning [5]. An end is valuable because it has intrinsic value and it is capable of arousing desire or appreciation. The value of a means depends upon its relation to an end: "Subsystem A is a means to Subsystem B, if A results in or causes B". This is a concise way of stating that the SAL subsystem solution attributes, once chosen, determine the design of an alternate system, or at the very least, influence its overall design.

The utility of a given solution attribute may be expressed as a mathematical function that can be extrapolated into a curve. Utility curves were not established for the SAL problem situation because such curves could not be fully relied upon as representing actual solution attribute worth. The construction of the utility curve usually involves the amalgamation of many technical, managerial, and operational value imputes that are provided by the experts. It is evident that a greater expenditure of time and manhours would be required to translate the utility functions into curves. Instead, relative utilities were established for each solution attribute and are provided as input to the decision algorithm as opposed to the actual utility curves and values. The relative utilities can be easily estimated with a reasonable degree of confidence. Moreover, where uncertainty exists in estimating the relative utility for a given attribute, it may be so noted by the assignment of a quantified number.

Table C-1 presents an emphasis coefficient ranking worksheet that shows the assignment of preference between solution attributes by appropriating numerical values per cell. The numerical values are a measure of utility between the solution attributes and indicate how the assignee feels about the relative value per solution attribute. The worksheet format delineates rows, columns, and cells. Fourteen solution attributes are listed (rows A through N). Likewise, fourteen decision columns (A through N) are listed and correspond to the attributes given in rows A through N. The solution attribute noted in row A is the same for column A. The same convention is used for the remaining rows and columns. A cell is formed where a row and column

intersect. Each cell is divided into an upper and lower triangular portion. The upper portion is used by registering a relative utility importance score between a pair of succeeding solution attributes, while the lower portion is used for denoting a decision uncertainty score between the same pairwise attributes. The utility interval used for the ranking of solution attributes is [ 0, 1 ]. If uncertainty is inherent in a decision situation, then the utility score is proportionally assigned among three constituent parts; that is the two solution attributes under consideration and the uncertainty associated with the attributes. Table C-2 presents the solution attribute emphasis coefficient ranking worksheet data in a processed automated format. Table C-3 presents the emphasis coefficient ranking of the relative utility per attribute and the uncertainty associated with the attribute.

## SYNTHESIZE SOLUTION ALTERNATIVES

Four solution alternatives were considered as possible candidates for resolving the SAL decision problem and are denoted at the beginning of Table A-4.

## THE EVALUATION OF THE CANDIDATE SOLUTION ALTERNATIVES

At this point, the SAL solution attributes and alternatives are combined and evaluated for expected performance, design compatibility, expected worth, and the impact of intangibles such as NASA Contractual Obligations and Cost. A trade-off study was conducted for the purpose of clearly defining and comparing the merits of the solution alternatives. (See Table A-4.) The explicit solution attributes, associated with the alternatives, were carefully analyzed to establish their responses with the minimum, average, and maximum performance threshold values (Table A-3, columns 2 and 3). Normally, the values derived from the response analysis for each candidate alternative would be referred to the appropriate solution attribute utility curves for the purpose of acquiring a set of utility numbers for each alternative. However, the approach used for establishing the relative utility (application of utility curves) for a solution attribute was not employed in this instance. (Refer to the explanations in "Rank Solution Attributes and Obtain Utility Curve" as stated above.) Instead, the relative utilities for the alternatives are estimated by using the preference ranking technique as previously described. Once again, the closed interval of [ 0, 1 ] is used, but this time for ranking the solution

alternatives and associated attributes. Table C-4 presents a series of system comparison trade-off evaluation worksheets that show the assignment of preference (ranking) between the solution attributes and the candidate alternatives. Table C-5 presents the system comparison trade-off ranking worksheet data in a processed automated format.

## ANALYZE ALTERNATIVE SOLUTIONS FOR ADVERSE CONSEQUENCES

Before choosing a SAL solution alternative that satisfies the decision criterion, it becomes necessary to review and analyze the solutions for adverse consequences. Further, it becomes necessary to define the states of nature associated with actions to be taken. Pursuant to the SAL decision problem, the states of nature are defined as: (1) MSFC will accomplish the SAL modification and installation task, and (2) an aerospace contractor will accomplish the SAL modification and installation tasks. The actions to be taken may be defined as choosing a SAL installation at: (1) alternate position 1, located on the STS (on-axis); (2) alternate position 2, located on the STS (off-axis); (3) alternate position 3, located on the MDA (on-axis); and (4) alternate position 4, located on the MDA (off-axis). It will be recalled that the SAL problem situation was so structured that the engineering and operational performance threshold values were to be maximized while cost and time were to be minimized. The objective is to choose a set of decision elements (an action and a state of nature) that best meets the decision criterion. By combining a given action with a given state of nature, it is now possible to isolate and identify the relative level of risk or expected utility, and the probability of success associated with that decision. Moreover, it is judicious to examine how the decision choice (consequences or outcomes) might affect the customer's philosophy. The SAL decision problem may be resolved as having four alternative acts and two possible states of nature, thus resulting in eight consequences (Table A-5).

Inspection of Table C-3 shows that the first seven solution attributes greatly influence the decision outcomes of performance, cost, feasibility, and time for each candidate alternative. The solution attributes may also be considered as risk criteria; i. e., what might be considered as a probable loss if the selected SAL position cannot fulfill its objectives and goals. The critical risks associated with the SAL problem situation are specified as

engineering feasibility, operational performance, capital, time, and responsible management philosophy. Further, it is necessary to estimate the probability of success for a selected SAL decision consequence ( $C_{ij}$ ) with respect to the objectives and goals. Such an estimate provides the evaluator with an insight into the feasibility of satisfying the decision criterion.

It is now possible to specify the consequences for a selected act and a corresponding state of nature (Tables A-6 through A-13). Inspection of Table A-14 shows that outcomes  $C_{12}$  and  $C_{11}$  have the greatest chance of success while  $C_{41}$  and  $C_{42}$  have the least chance of success. This estimate of success is based on a subjective consideration that the solution attribute of NASA Contractual Obligations and Cost will ultimately sway the final decision to choose either  $C_{12}$  or  $C_{22}$ . This fact does not invalidate the decision input data. On the contrary, the decision input data (solution attributes and alternatives) permit the evaluator to consider all relevant facts and how those facts might be manipulated. The fact that the present location of the AAP experiment structural framework assembly for T-017 and T-021 severely impacts the AAP-3/AAP-4 mission requirement, if SAL alternate position 3 or 4 is selected, does not invalidate the decision analysis, but rather identifies an acute problem area. This problem could possibly be resolved by relocating the T-017 and T-021 experiment framework structure to a different location, say closer to SAL alternate position 4, then the probability of outcomes  $C_{41}$  and  $C_{42}$  succeeding would greatly increase while those of  $C_{11}$  and  $C_{12}$  would be materially reduced. The probability of success for any given outcome is really a subjective measure of how the evaluator feels about consequences influencing the final decision.

## THE SELECTION OF A SOLUTION ALTERNATIVE THAT SATISFIES THE DECISION CRITERION

The merit scores and uncertainties for each competitive solution alternative are calculated by using the decision algorithm and are presented in Table C-6. Inspection of Table C-6 illustrates that SAL alternate position 4 is the first choice, while merit choices 2 and 3 are allotted to SAL alternate positions 1 and 2. An apparent conflict exists between Tables C-6 and A-14. An analysis of this fact shows that the algorithm decision input data were heavily weighted in favor of SAL alternate position 4. This would not be unusual for this particular decision situation. The interpretation of the decision data clearly indicates that the advantages of minimum cost, minimum engineering modification effort, minimum impact to AAP mission schedules, and no interfacility transportation requirements slightly outweighed the inherent AAP

intangibles such as NASA Contractual Obligations and Cost which will undoubtedly play an important role in the final decision choice. It is necessary to review Tables C-6 and A-14 and put them in the proper perspective before a final decision choice is recommended. Table C-6 shows that there is only a slight difference between ranked alternatives 1 and 2. However, Table A-14 shows that outcomes  $C_{12}$  and  $C_{11}$  greatly exceed the chances of success of  $C_{41}$  and  $C_{42}$ . The interpretation of these facts indicates that SAL alternate position 1 is really a better choice than alternate position 4. It must be remembered that the selection of SAL alternate position 1 can better fulfill the decision criterion (although at a substantially higher cost). It is obvious that SAL alternate position 4 can minimize cost and time while maximizing expected engineering value, but cannot maximize operational value. Further, SAL alternate position 4 cannot support AAP-3/AAP-4 experiment mission requirements, whereas SAL alternate position 1 can support the mission experiments. It is also anticipated that MSFC will select an aerospace contractor who is familiar with the AM/STS structural module to perform the SAL modification and installation effort, because such a contractor would already have contractual obligations with NASA for providing AM/STS engineering and manufacturing support services.

It is recommended that SAL alternate position 1 be selected as the first choice, and SAL alternate position 2 selected as a second choice. If the T-017 and T-021 experiment framework structure assembly can be relocated near SAL alternate position 4, or deleted from the mission requirement, then choose SAL alternate position 4.

## CONCLUSIONS

The decision model and algorithm, as presented in this document, offers both the engineer and manager an orderly methodology for making complex decisions based on tangible facts, considered opinions, and intangible considerations. The methodology is so structured that consistency is maintained between the facts, opinions, and considerations. The technique contained herein reduces complex decision problems and situations to component elements that are easily managed. Each component element is evaluated in terms of value by either establishing a point on a utility curve or, as used in Appendix A, estimating the relative utility between two component elements (solution attributes and solution alternatives). Consideration is given to the selected actions and states of nature for a particular decision outcome, and its consequences. Finally, the decision model and algorithm display the relevant

data in such a fashion that the decision maker knows what information is missing, where his critical risks lie, what criteria is salient, and what courses of action may be selected with a high degree of confidence.

Pursuant to the sample decision problem contained in Appendixes A through C, it is recommended that alternate position 1 be chosen to resolve the SAL modification, installation and AAP mission operational requirement problems. This choice is based on the premises that alternate position 1 best satisfies the decision rule, stated as the primary objective, and has the greatest probability of success.

Invaluable experience was gained while using the decision model and algorithm on the above practical engineering problem. On a number of occasions the user attempted to make a rational decision concerning the optimum choice location of the SAL, but was thwarted. It was found that the user's ranking of solution attributes was sometimes inconsistent, or inadequate information was biasing the decision choices, or excessive importance was placed on a solution attribute that was relatively unimportant, etc. Once the above problems were resolved, the decision maker could proceed with the formulation of a rational decision. The decision model and algorithm is an unforgiving analytical tool that forces the user to maintain consistency of choices, consider the consequences of the decision before it is implemented, and become cognizant of the veracity of the information on which the decision choices are formulated.

TABLE A-4. DECISION ANALYSIS AND EVALUATION WORKSHEET

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
	<p>Proposed location: secured to the inner wall structure of the AM at position 1 (coincident with respect to the -Z and X axes) of the STS at MSFC Station 1858, 569. (See Fig. A-1.) The SAL exterior door would be oriented to open perpendicular to the Z axis but parallel to the X-Y axes.</p>	<p>Proposed location: secured to the inner wall structure of the AM, centered 45 degrees between positions 1 and 2 (off-axis) of the STS at MSFC Station 1858, 569. (See Fig. A-1.) The SAL exterior door would be oriented to open perpendicular to the Z axis, but parallel to the X-Y plane.</p>	<p>Proposed location: secured to the inner wall structure of the MDA directly below docking port 1 (coincident with respect to the -Z and X axes) at MSFC Station 1847, 069. (See Fig. A-1.) The SAL exterior door would be oriented to open perpendicular to the Z axis, but parallel to the X-Y axes.</p>	<p>Proposed location: secured to the inner wall structure of the MDA, centered 45 degrees between docking ports 1 and 2 (off-axis) at MSFC Station 2027, 069. (See Fig. A-1.) The SAL exterior door would be oriented to open perpendicular to the Z parallel to the X-Y plane. Alternate position 4 is in fact the present location of the SAL as attached to the MDA per Technical Reference 29 (sheets 1 and 2). For the purpose of this decision example, position 4 shall be considered as an alternate location for the SAL.</p>
Modification of the Structure	<p>The MDA is interfaced to the AM/STS structure at MSFC Station 1882, 069. To prepare the STS for structural modification, the longitudinal and radial mobility aid handrails and radiator assembly, mounted external to the MDA and STS, must be removed. All system interconnecting lines and cables at MSFC Station 1882, 069 must be disconnected, MDA/STS interface pressure seals broken, MDA/STS bulkhead field splice fasteners disengaged, and the above structural sections separated physically. Heavy duty handling equipment and transporters will be required to support the disassembly effort.</p> <p>A cursory analysis of the STS structure shows that the SAL, if mounted horizontally, can be fitted between the intermediate structural rings at Stations 15, 666 and 31, 332 (Fig. A-2). The SAL oriented in this manner should fall between the intercostal tee stringer sections and clear the webbing. A cutout in the STS pressure skin would have to be provided for the SAL at position 1. Additional STS rework will be required to provide a structural pressure skin. Any system carrier lines (electrical, pressurization, etc.) passing through the immediate area affected by the modification must be rerouted. Proper sealing of the reworked area and pressure testing to determine the integrity of the STS structure will be required.</p> <p>It is anticipated that the AM contractor's net cost for modifying the STS structure is calculated at \$209,060.00, or approximately 36 percent less than the normalized case at alternate position 2. All costing data for Appendix A is detailed and submitted in Appendix B, Tables B-1 through B-5. The cost pricing figures presented therein</p>	<p>The interface and handling problems that were defined for alternate position 1 are identical for alternate position 2. The structural modification problems that were outlined for position 1 will be similar for position 2. It should be easier, however, to modify the STS structure since a window cutout has already been made, and greater clearance between intercostal tee stringer sections will offer less chance of SAL mounting interference. Again, it will be necessary to seal the reworked area, and pressure test the STS structure for integrity.</p> <p>It is anticipated that the AM contractor's net cost for modifying the STS structure would be \$327,600.00.</p>	<p>The MDA is interfaced to the AM/STS structure. To prepare the MDA for structural modification, the longitudinal and radial mobility aid handrails and the radiator assembly (mounted external to the MDA and STS) must be removed. Only a minimum of heavy duty handling equipment will be required to support the radiator disassembly effort.</p> <p>Examination of Reference 29 (sheet 4) indicates that the SAL can be located at MSFC Station 1947, 069, and optimally oriented in the horizontal position. It is intended that the SAL be centered with respect to the X-Z plane, thus clearing all MDA longitudinal stringers and circumferential bellframes in the immediate panel area. A cutout in the MDA pressure vessel walls and additional structural rework to provide a framework support bracket for the SAL will be required. Proper sealing of the reworked area and pressure testing to determine the integrity of the MDA structure will be required.</p> <p>If NASA were to implement the modification to the structure at MSFC for alternate position 3, the net cost is calculated at \$172,680.00, or approximately 47 percent less than the normalized case at alternate position 2. If a contractor were to undertake the above structural modification at their facility, then the net cost is calculated at \$233,150.00, or approximately 28 percent less than the normalized case at alternate position 2. A cost comparison between a contractor's figures and NASA figures could indicate that the latter can accomplish the task for \$60,470.00 less than the contractor. This represents a 26 percent cost savings to NASA.</p>	<p>The MDA is interfaced to the AM/STS structure. No special preparations or GFE handling equipment will be necessary to modify the MDA structure, if it is done at MSFC. No disassembly of major MDA or STS components would be required.</p> <p>If the SAL is oriented vertically to the MDA wall, it can be adequately mounted and aligned. The SAL would be located near MSFC Station 2027, 069, and centered 45 degrees between the -Z and +Y axes. This orientation and location should clear all MDA longitudinal stringers and interfering circumferential bellframes in the immediate panel area. A cutout in the MDA pressure vessel walls, and additional structural rework to provide a framework support bracket for the SAL will be required. Proper sealing of the reworked area and pressure testing to determine the integrity of the MDA structure will be required.</p> <p>If a contractor were to implement the modification of the MDA structure at their facility, the calculated net cost would be \$224,770.00, or approximately 31 percent less than the normalized case as given in alternate position 2. If, however, MSFC were to implement the above structural modification, then the net cost is calculated at \$176,010.00, or approximately 46 percent less than the cost expended for the normalized case. A comparison of cost differential between the contractor and NASA shows that the latter can save \$48,760.00 if it accomplishes the task in-house. This would result in a 22 percent cost savings to NASA.</p>

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
	represent considered judgements based upon past contract pricing practices, experience, and reasonable approximations. The cost pricing figures are, however, not to be construed as official NASA cost quotations.			
Radiator Modification	<p>The STS/MDA external radiator assembly must be modified if the SAL is located at alternate position 1. A minor structural cutout would have to be provided in the radiator walls, and rerouting of carrier tubing around the SAL installation would have to be made. Additional stand-off fittings would probably be required to support the modified structure and rerouted tubing. No major structural rework is anticipated.</p> <p>It is anticipated that a contractor would charge NASA \$94,660.00 to modify the radiator. This figure represents approximately 42 percent less net cost as compared to the normalized case at alternate position 2.</p>	<p>Only minor structural rework of the radiator wall assembly is anticipated if the SAL is located at alternate position 2. A cutout provision in the radiator wall structure has already been made for the STS windows. No rerouting of radiator carrier tubing is expected. Probably additional stand-off fittings will be required to support the modified structure near the SAL installation. Minimum radiator modification would occur under this decision criteria.</p> <p>The expected net cost to NASA for the modification of the radiator by a contractor is calculated at \$163,800.00.</p>	<p>If SAL alternate position 3 were chosen, then the radiator assembly external to MSFC Station 1947,069 must be modified. A structural cutout would be needed in the radiator walls, and rerouting of carrier tubing around the SAL would be made. Additional stand-off fittings would probably be required to support the modified structure and rerouted tubing. Only minor structural rework to the radiator is anticipated.</p> <p>The anticipated net cost to modify the radiator for NASA by a contractor is calculated at \$104,280.00, or approximately 36 percent less expense as compared to the normalized case. The same task as described above would cost NASA \$91,900.00 if they were to accomplish the job at MSFC. This figure represents a cost savings of approximately 44 percent as compared to the normalized case. A comparison of cost differential between the contractor and NASA shows that the latter would stand to gain \$22,380.00, or a 12 percent savings if the job were accomplished at MSFC.</p>	<p>No radiator modification would be required if the SAL is located at alternate position 4. No cost is incurred by NASA or a contractor. The radiator assembly does not extend beyond MDA Station 1962,749.</p>
Relocation of Internal Hard Mounted Equipment	<p>Analysis of technical Reference 31 shows that the quantity of equipment in alternate position 1 is heavy. The molecular sieve assembly is presently located in the STS section with an overall width of about 28.41 inches. The sieve assembly is mounted perpendicular to the STS interior wall structure with most of the assembly aligned symmetrically to the -Z axis. The molecular sieve assembly would have to be relocated in order to provide room for mounting the SAL at position 1. The likelihood of system pressurization lines, electrical cables, life support systems, or mobility aids and handrails interfering with the location of the SAL at this position is small. Complete and up-to-date information concerning the above equipment location in the STS was not readily available.</p> <p>It should be understood that the location of experiment storage packages, equipment, and lines in the STS are not finalized at this time. It is anticipated that some experiment</p>	<p>A review of Reference 31 reveals that the quantity of equipment in alternate position 2 is light. Only two unidentified storage containers are shown directly adjacent to alternate position 2. The storage containers must be relocated within the STS or MDA. Once the containers are removed adequate STS wall mounting area for the SAL is available.</p> <p>Reference 31 does not specify an STS window cutout 45 degrees clockwise from the +Y axis as was defined in Reference 32. Furthermore, it should be noted that if the 45-degree STS window position were used for locating the SAL, then the T-027 experiment photometer extension rod canister would interfere with the IVA suit coolant module when interfaced to the SAL. Either the IVA suit coolant module would have to be relocated, or the SAL would have to be relocated 35 degrees from the -Z axis (in the direction of the +Y axis) to clear the photometer canister assembly. A third alternative would be to reduce</p>	<p>The quantity of equipment in alternate position 3 is moderate. The MDA upper equipment storage boxes for experiments M-508 and M-487 must be removed and relocated. The upper mobility personal equipment storage bay must be relocated. (Refer to MDA position 1, Reference 29, sheet 4.) The relocation of the above boxes and bay area is necessary for the provision of a mounting space for the SAL. No MDA interior system pressurization lines, electrical cables, life support systems, or mobility aids and handrails are to be affected by the locating of the SAL to this position.</p> <p>It may be necessary to restow MDA experiment storage boxes M-487 (two each) and the lower M-508 package to some other position in the MDA when using the SAL. If the astronaut can easily gain access to the SAL during experiment operations, it may not be necessary to restow the above boxes.</p>	<p>The quantity of equipment in alternate position 4 is light. There are six experiment storage boxes in the immediate vicinity. The largest of the storage boxes is the T-013 Crew Disturbance package. This package is located below the proposed location of the SAL. It is anticipated the storage box T-013, as well as the others on the adjacent MDA wall mounting panel, will not interface with or impede the astronaut's operation of the SAL.</p> <p>It has been reported that MDA experiment storage package T-027, located below the proposed SAL installation and next to storage package T-013, may be deleted from the MDA. It is obvious that the locations of MDA experiment storage packages have not been finalized.</p> <p>If NASA were to accomplish the relocation of hard-mounted equipment in the MDA at MSFC, the net cost is calculated at</p>

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
	<p>packages, equipment, and lines will either be relocated or deleted from the STS because changing engineering or mission requirements.</p> <p>The net cost of relocating the hard-mounted equipment in the STS is \$282,555.00, if a contractor were to accomplish this task. This cost is 15 percent greater than that specified in the normalized case. (See alternate position 2.)</p>	<p>the photometer extension rod canister size (diameter and/or length) to clear the IVA suit coolant module assembly, if the 45-degree STS position were used for locating the SAL. It is not likely that any system pressurization lines, electrical cables, life support systems, or mobility aids and handrails will interfere with the location of the SAL within a 37.5 to 59-degree angular segments measured from the +Y axis.</p> <p>The above situation indicates that the requirements for the location of experiment storage packages, equipment, system carrier lines, and even observation windows within the STS are still being analyzed. It is anticipated that some or all of the above items may either be relocated or deleted from the STS because of changing engineering or mission requirements.</p> <p>It is expected that a contractor would charge NASA \$245,700.00 for relocating the equipment in the STS.</p>	<p>Again, it should be understood that the location of experiment storage packages in the MDA are not finalized at this time. It is anticipated that some experiment packages will either be relocated or deleted from the MDA because of changing engineering or mission requirements.</p> <p>If a contractor were to relocate the pertinent equipment in the MDA (for the provision of a SAL mount), the net cost is calculated at \$165,847.50, or approximately 32 percent less than the normalized case. If MSFC were to accomplish the above task, then the cost would be \$98,280.00, or approximately 60 percent less than the normalized case.</p> <p>If NASA were to accomplish the above task instead of a contractor, then \$67,567.00 could be saved by NASA. This figure represents a cost savings of approximately 41 percent.</p>	<p>\$30,712.50, or approximately 87 percent less than the normalized case. A contractor would probably charge about \$49,140.00 to accomplish the same task. The contractor's estimate represents approximately a 60 percent reduced cost as compared to the normalized case. Comparing the cost between the contractor and NASA to perform the above task, the latter could save \$18,427.50, or 37 percent of the expense.</p>
Reflection and Outgassing from T-017 and T-021	<p>In considering the reflection, outgassing, and contamination problems associated with alternate position 1, the AAP externally mounted experiments T-017 and T-021 panels and structural framework are positioned approximately 11.5 inches directly below the SAL (Figs. A-3 and A-4). A distance of 96.75 inches is calculated between the outboard face of the SAL and the outboard end of the framework assembly. Experiments T-017 and T-021, either stored or deployed, should offer no interference with the SAL or to those experiments operating through the SAL assembly. The panel and structural framework would be deployed in such a fashion as to clear the LM/ATM module.</p> <p>It is anticipated that AAP experiments T-017 and T-021 will not excessively outgas or reflect micrometeoroid particles that could cause inner compartment contamination or damage in the direction of the SAL. The design of the SAL is such that the outer door assemblies, when closed, provide a positive seal against inner compartment contamination and damage. The SAL doors are only opened for a relatively short period of time (minutes and hours) to support contamination measurement and micrometeoroid</p>	<p>Assuming that the SAL were located in alternate position 2, then the AAP externally mounted experiments T-017 and T-021 framework and panel assemblies would be positioned on a horizontal plane approximately 11.5 inches below and 45 degrees to the right of the SAL, as viewed from within the STS. A distance of 121.75 inches is calculated between the outboard face of the SAL and the outboard end of the framework structure. Experiments T-017 and T-021 should offer no interference problems with the SAL, or with those experiments operating through the SAL assembly. The experiment panel and structural framework would be deployed in such a manner as to clear the LM/ATM module and SAL.</p> <p>No problems of outgassing, contamination, and particle reflection (as defined in alternate position 1) are anticipated.</p>	<p>Alternate position 3 for the SAL would present some problems. The AAP experiments T-017 and T-021 would be positioned approximately 100 inches directly below the SAL. A distance of 138.56 inches is calculated between the outboard face of the SAL and the outboard end of the framework structure. The experiment structural framework and paneling should offer no interference problems with the SAL operation, but other AAP experiments that must operate through the SAL assembly and reach the near proximity of experiments T-017 and T-021, for contamination measurement and collecting purposes, may not be easily accomplished. Inspection of Reference 29 (sheet 2) illustrates that approximately 8 to 16 inches of clearance exist between the SAL and the LM Structure when docked to the MDA. The proximity of the above modules will more than likely cause operational problems for AAP-2 and AAP-4 experiments S-018, T-025, and T-027 which must operate through the SAL. These experiments require the use of long extension rods or devices to be extended outward from the Orbital Workshop through the SAL. It is anticipated that experiments S-018, T-025, and T-027 will interfere with the LM structure when operated through the SAL at alternate position 3.</p>	<p>If alternate position 4 is selected for locating the SAL, then similar operational problems and interference constraints would apply as defined in alternate position 3. AAP experiments T-017 and T-021 panel and structural framework would be located on a horizontal plane approximately 180 inches below and 45 degrees to the right of the SAL, as referenced from within the MDA. A distance of 217.0 inches is calculated between the outboard face of the SAL and the outboard end of the framework structure. Experiments T-017 and T-021 should offer no interference problems with the SAL.</p> <p>No problems of outgassing, contamination, and particle reflection (as defined in alternate position 1) are anticipated.</p>

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
	<p>collection experiments. Those AAP experiments that are operated through the SAL for measurement and collection purposes would offer no contamination to experiments T-017 and T-021.</p> <p>The major outgassing flux is expected to be from the 5 psi atmosphere contained within the Orbital Workshop. Any outgassing of atmosphere or unexpected contaminants, trapped or vented, as measured against the Orbital Workshop flux would be negligible.</p> <p>When using the Lunar Module RCS packages, both the T-017 and T-021 experiments and SAL would be retracted, closed, and sealed against exhaust contaminants.</p>		<p>No problem of outgassing, contamination, and particle reflection (as defined in alternate position 1) are anticipated.</p>	
Near Control Station	<p>It is anticipated that the glide-slope indicator will be remotely located from the SAL control station. All essential instruments and levers that are used to operate and control the SAL are designed into the assembly. It has been assumed that the glide-slope indicator shall be mounted on the MDA docking station panel. The MDA docking station panel location has not been finalized and is to be determined (TBD). For the purpose of this study, the MDA docking panel is assumed to be located as shown in Figure A-5. It is calculated that a line-of-sight distance from the control panel assembly to the inboard face of the SAL is approximately 153 inches.</p> <p>It is expected that the astronaut would have work clearance and light to operate and read the SAL control station systems during mission test operations. If a readout of the glide-slope indicator is required then the astronaut must obtain this information by a communications link between the Command Pilot in the CSM, or a crew member located next to the MDA docking station panel.</p>	<p>The comments expressed for alternate position 1 apply for alternate position 2 in the STS, except the line-of-sight distance is calculated at 159 inches between the inboard face of the SAL and the MDA docking control panel.</p>	<p>Considering alternate position 3, the glide-slope indicator is still remote from the SAL control station, but much closer and access is easier (Fig. A-5). The same comments as expressed for alternate positions 1 and 2 also apply for the MDA.</p>	<p>With respect to alternate position 4, the glide-slope indicator is still remotely located from the SAL control station, but is considered to be closer and easier to gain access to than any of the other alternatives. It is calculated that a line-of-sight distance from the MDA control panel to the inboard face of the SAL is approximately 46.25 inches. If the glide-slope indicator can be oriented on the MDA docking station panel to provide a line of visual sight to the astronaut, then the requirement of locating the glide-slope indicator near the SAL control station can be adequately met. All essential instruments and levers that are used to operate and control the SAL are designed into the assembly.</p>
SAL Extension Rod Clearance	<p>Three AAP measurement and collection experiments are expected to be operated through the SAL in support of several AAP-4 experiments. Experiment S-018 is performed during both AAP-2 and AAP-4 missions. Experiments T-025 and T-027 are performed during AAP-2, AAP-3, and AAP-4 missions, but support primarily the AAP-4 mission.</p>	<p>The same AAP experiments, as defined in alternate position 1, would be interfaced with the SAL in alternate position 2.</p> <p>It is assumed that two unidentified storage containers, located in the STS between the -Z and +Y axes, have been relocated, and that adequate clearance exists between the T-027 photometer canister and the IVA suit coolant</p>	<p>The same AAP experiments, as defined in alternate position 1, would be interfaced with the SAL in alternate position 3.</p> <p>It is assumed that MDA upper equipment storage boxes for experiments M-508 and M-497 have been relocated, and that the upper mobility personal equipment storage bay is also relocated. It is also assumed</p>	<p>The same AAP experiments, as defined in alternate position 1, would be interfaced with the SAL in alternate position 4.</p> <p>Analysis of Reference 29 shows that when the T-027 photometer extension rod canister is attached to the SAL, physical interference is established between the canister assembly and experiment S-069 storage package. The</p>

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
	<p>It is assumed that the molecular sieve has been relocated in the STS, thus permitting the mounting of the SAL at alternate position 1. An additional 24 inches of mechanical extension rod will extend beyond the T-027 photometer canister when the canister is mounted to the SAL. It is anticipated that experiments S-018 and T-025 will require similar extension rod lengths (36 inches maximum) to be assembled within the STS interior and pushed out the SAL assembly by the astronaut. Adequate extension rod clearance is available, and no equipment or astronaut interference problems are anticipated for the interior of the STS.</p> <p>No mechanical interference problems are anticipated for the operation of the extension rod from the SAL outboard of the STS.</p>	<p>module to permit the interface of the canister to the SAL. It is further assumed that the above equipment is relocated in such a manner that it will not interfere with the SAL extension rods.</p> <p>An additional 24 inches of mechanical extension rod will extend beyond the T-027 photometer canister. Similarly, experiments S-018 and T-025 will require extension rod lengths (36 maximum) to be assembled within the STS interior and pushed out the SAL assembly. Adequate extension rod clearance is available, and no equipment or astronaut interference problems are anticipated for the interior of the STS.</p> <p>No mechanical interference problems are anticipated for the operation of the extension rod from the SAL outboard of the STS.</p>	<p>that the above storage boxes are relocated in such a manner that they will not interfere with the SAL extension rods.</p> <p>An additional 24 inches of mechanical extension rod will extend beyond the T-027 photometer canister. Similarly, experiments S-018 and T-025 will require extension rod lengths (36 maximum) to be assembled and pushed out the SAL assembly. Adequate extension rod clearance is available, and no equipment or astronaut interference problems are anticipated for the interior of the MDA.</p> <p>It is anticipated, however, that the extension rod operational support requirements for AAP experiments S-018, T-025, and T-027 cannot be met. Approximately 8 to 16 inches of clearance exist between the SAL and the LM structure when docked to the MDA. The proximity of the MDA and LM structures will interfere with the extension rods. The extension rods cannot be readily extended outward from the MDA when operated through the SAL.</p>	<p>S-069 experiment storage package (located directly above MDA docking port 2) must be relocated to clear the canister and SAL extension rods.</p> <p>An additional 24 inches of mechanical extension rod will extend beyond the T-027 photometer canister when the canister is interfaced to the SAL. It is anticipated that experiments S-018 and T-025 will require similar extension rod lengths (36 inches maximum) to be assembled and pushed out of the SAL assembly. With the S-069 experiment storage package removed, adequate extension rod clearance will be made available. No equipment or astronaut interference problems are expected for the interior of the MDA.</p> <p>It is anticipated that AAP experiments S-018, T-025, and T-027 will experience the same operational interference problems as were described in alternate position 3.</p>
Crew Obstructions	<p>When the T-027 experiment photometric extension rod canister is interfaced to the SAL at alternate position 1, it offers a greater astronaut crew obstruction than if it were mounted on the SAL at alternate position 2. It is anticipated that an additional 24 inches of extension rod will be extended beyond the end of the photometric canister assembly, thus offering even greater crew obstruction within the STS (Fig. A-6).</p> <p>Astronaut working clearance and ease of maneuverability at position 1 will be greater than for position 2. The overall astronaut working clearance and ease of maneuverability in the STS as compared to the MDA will be somewhat less, however. The bulk size of equipment (molecular sieve, IVA suit coolant module, ECS storage canister, control panel, and condensate control unit) located in the STS section, as well as the storage packages, are expected to limit the astronaut's ability to work at ease and maneuver freely.</p>	<p>See comments made under alternate position 1. The astronaut working clearance for alternate position 2 will be even more constrained than was defined in alternate position 1.</p>	<p>When the T-027 experiment photometric extension rod canister is interfaced to the SAL at alternate position 3, it offers a greater astronaut crew obstruction than if it were mounted on the SAL at alternate position 4. As was anticipated in alternate position 1, an additional 24 inches of extension rod is expected to extend beyond the canister assembly, thus offering greater crew obstruction within the MDA (Fig. A-7).</p> <p>The astronaut working clearance and ease of maneuverability at position 3 will be greater than for alternate position 4. The overall astronaut working clearance and ease of maneuverability will be somewhat greater in the MDA than in the STS.</p>	<p>See comments made under alternate position number 3.</p>

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
Wall Area Consumed by SAL	Approximately 315 in. <sup>2</sup> of STS interior wall surface area would be consumed by locating the SAL at alternate position 1. It is estimated that the overall SAL length and width, including mounting bracket, is 21 inches by 15 inches. With the experiment T-027 photometer extension rod transfer canister attached to the SAL, a maximum X-Z plane cross-sectional area of approximately 380 in. <sup>2</sup> is calculated. The alignment of the canister is coincidental with the -Z axis and extends approximately 40 inches into the STS (Fig. A-6).	Approximately 325 in. <sup>2</sup> of STS interior wall surface area would be consumed by locating the SAL at alternate position 2. It is estimated that the overall SAL length and width, including mounting bracket, is 21.3125 inches by 15.250 inches. Approximately 380 in. <sup>2</sup> is calculated for the T-027 photometer extension rod transfer canister cross-section when attached to the SAL. The photometer canister is aligned parallel to the -Z axis, but perpendicular to the X-Y plane (Fig. A-6).	Approximately 315 in. <sup>2</sup> of the MDA interior wall surface area would be consumed by locating the SAL at alternate position 3. Approximately 380 in. <sup>2</sup> is calculated for the T-027 photometer extension rod transfer canister cross-section. The canister assembly is coincidental with the Z axis and extends approximately 40 inches into the MDA (Fig. A-7).	Approximately 325 in. <sup>2</sup> of MDA interior wall surface area would be consumed by locating the SAL at alternate position 4. The same cross-sectional area is calculated for the T-027 photometric canister as given in the other alternate positions. The transfer enclosure is oriented in similar manner as specified in alternate position 2 (Fig. A-7).
Launch Storage Area Available Over SAL	Approximately 196 in. <sup>2</sup> of storage area is available directly over the SAL, after the molecular sieve is relocated (Figs. A-8 and A-9). It is anticipated that the storage area would be cleared after Orbital Workshop activation thus minimizing the chance of obstruction, and providing maximum astronaut working clearance in the STS at alternate position 1.	Refer to comments made for alternate position 1. The same dimensional clearance exists for storage area above the SAL, after two unidentified storage packages are removed from alternate position 2 and re-located. (See Reference 31.)	No useful storage area is available over the SAL when located at alternate position 3. The MDA docking port 1 structural ring assembly is approximately 8 inches from the top of the SAL assembly.	No useful storage area is available over the SAL when located at alternate position 4. The MDA upper cone frustum would interfere with the location of launch storage area over the SAL.
Transportation	It is anticipated that the net cost of shipping the STS/MDA to and from a contractor's facility would be approximately \$81,900.00. All necessary support equipment for the handling, shipping, and ensuring the structural safety of the STS/MDA is expected to be available.	It is anticipated that the net cost of shipping the STS/MDA to and from a contractor's facility should be the same as alternate position 1 selection. All necessary transportation support equipment is expected to be available.	It is anticipated that the net cost of shipping the MDA to and from a contractor's facility would be approximately \$81,425.00. If NASA chose to perform all of the necessary modification on the MDA at MSFC, then the net cost of interdepartmental and intrafacility shipping would be about \$2,047.50. All necessary transportation support equipment is expected to be available.	The net transportation cost as defined in alternate position 3, for both a contractor or NASA, is applicable to alternate position 4. All necessary transportation support equipment is expected to be available.
Schedule Effects, Impact Against SAL Installation	It is a considered opinion, in the face of other STS/MDA schedule uncertainties, that approximately 35 working days will be required to remove and relocate affected internal STS hardware, modify the STS structure and radiator wall assembly, and install the SAL. An additional 10 working days will be required to reassemble the radiator assembly to the STS/MDA structure.	Approximately 30 working days will be required to modify the necessary STS and radiator structure and install the SAL at alternate position 2. This estimate is based on considered opinion and is subject to other STS/MDA schedule uncertainties. An additional 10 working days will be required to reassemble the radiator assembly to the STS/MDA structure.	Approximately 25 working days will be required to modify the necessary MDA and radiator structure, and install the SAL. This estimate is based on considered opinion and is subject to other MDA schedule uncertainties. An additional 10 working days will be required to reassemble the radiator assembly to the MDA and STS structure.	Approximately 20 working days will be required to modify the MDA structure and install the SAL. This estimate is based on considered opinion and is subject to other MDA schedule uncertainties.
Schedule Effects, Impact Against AAP-2 Mission	It is a considered opinion, in the face of other AAP-2 mission schedule uncertainties, that approximately 4 calendar months will be needed to complete all essential modification, installation, reassembly, testing, qualification, and supporting tasks that satisfy the SAL requirements.	Approximately 3.5 calendar months will be needed to complete all essential and supporting tasks that satisfy the SAL requirements. This time estimate is based on a considered opinion and is subject to other AAP-2 schedule impacts.	Approximately 3 calendar months will be needed to complete all essential and supporting tasks that satisfy the SAL requirements. This time estimate is based on a considered opinion and is subject to other AAP-2 schedule impacts.	Approximately 2.5 calendar months will be required to complete the necessary and supporting tasks that satisfy the SAL requirements. This time estimate is based on a considered opinion and is subject to other AAP-2 schedule impacts.

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
Use During Mission AAP-3/AAP-4	<p>Installation of the SAL at alternate position 1 (Fig. A-3) will not interfere with the operation of AAP experiments S-018, T-025, and T-027. It is anticipated that these experiments can be operated through the SAL and can accomplish their required operations in support of the AAP-3/AAP-4 missions. No LM or STS/MDA structural interference problems are anticipated. The structural hardware and assemblies for experiments T-017 and T-021 are located directly below the SAL at alternate position 1 (Fig. A-4) and should not interfere with experiments S-018, T-025, and T-027.</p>	<p>The comments dealing with structural and experiment interference problems, as defined for alternate position 1, apply to alternate position 2. The only exception to the previous statements would be the specific location of the SAL with respect to the structural framework and hardware for AAP experiments T-017 and T-021. The SAL would be located slightly above and approximately 45 degrees to the right, as viewed from the outside of the STS along the -Z axis, of the T-017 and T-021 experiment framework assemblies. It is assumed that 96 inches of extension rod length (Fig. A-6) would extend beyond the SAL for the purpose of servicing the AAP experiments attached to the framework structure. The SAL located in position 2 will impact the experiment service operational requirements since the extension rods cannot reach the outboard end of the structural framework. An additional 25.75 inches of extension rod length will be required (Fig. A-10, line g).</p>	<p>The installation of the SAL at alternate position 3 presents some major interference and operational problems for AAP experiments S-018, T-025, and T-027. Experiments T-017 and T-021 will be located approximately 100 inches directly below the SAL, but experiments S-018, T-025, and T-027, which must be operated through the SAL assembly and reach the near proximity of experiments T-017 and T-021, may not be easily accomplished. Figure A-6 shows that 96 inches of extension or push rod length extends beyond the SAL outboard of the MDA. It is not known whether this extended length is the maximum required, but if this is the case, then an additional 138.5 inches is needed to reach the near proximity and outboard ends of the T-017 and T-021 experiments framework and panels from the SAL at alternate position 3 (Fig. A-10, line h). Furthermore, a clearance problem exists for the SAL extension and push rod related experiments. There are only 8 to 16 inches of space between the SAL and the LM structure when docked to the MDA. This situation will cause operational problems for the AAP collection, contamination, and photometric measurement experiments. Experiments S-018, T-025, and T-027 require the use of a long extension rod to be extended outward from the MDA through the SAL. It is anticipated that the extension rod operational support requirements for AAP experiments S-018, T-025, and T-027 cannot be met and will interfere with the LM structure when operated through the SAL at alternate position 3.</p> <p>The selection of the SAL at alternate position 3, from an engineering and modification cost point-of-view, indicates that this position is a better choice than either alternate position 1 or 2. There is: (1) less structural modification and cost; (2) less relocation of major internal equipment; (3) less chance of micrometeoroid reflection, outgassing, and contamination of the SAL; (4) a shorter distance to the MDA control panel and glide-slope indicator; (5) less chance of internal MDA Scientific Airlock extension rod interference problems; and (6) less overall modification cost. However, the selection of the SAL at alternate position 3 from an operational point-of-view indicates that this</p>	<p>If alternate position 4 is selected for locating the SAL, then similar, if not more severe, operational problems and interference constraints for AAP experiments S-018, T-025, and T-027 would apply as defined in alternate position 3. Experiments T-017 and T-021 would be located approximately 217 inches below and 45 degrees to the right of the SAL, as viewed from inside the MDA. This SAL location not only presents a difficult task to reach the near proximity of the T-017 and T-021 experiments, but an additional 121 inches of extension rod is required (Fig. A-10, line i). Moreover, the same type of extension rod and LM structure interference problem exists when experiments S-018, T-025, and T-027 are operated through the SAL at alternate position 4. A clearance of 25 to 33 inches is calculated between the LM structure and SAL.</p> <p>The selection of the SAL at position 4, from an engineering and modification cost point-of-view, indicates that this position is even a more lucrative choice than alternate position 3. However, the selection of the SAL at position 4 from an operational support point-of-view indicates that this position is the least likely to succeed in fulfilling its mission support function.</p> <p>If the decision is made to select alternate position 4, then similar courses of corrective action must be undertaken to offset AAP experiment and LM structure interference problems as described in alternate position 3. It is estimated that 5 to 8 months of AAP program schedule stretch-out time will be required to effect the design, fabrication, and interface of an omni-directional extension rod to the MDA/SAL at position 4.</p>

TABLE A-4. (Continued)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
			<p>position is impractical and would seriously compromise the AAP-3/AAP-4 mission support requirements.</p> <p>If the decision is made to select alternate position 3, then several means of offsetting the undesirable interference and operational support problems must be found. For example, a programmed, remote-controlled, omni-directional extension rod linkage design might be employed (interfaced to the MDA/SAL) and designed so as to clear the LM structure and reach the required distances. The consequences of this decision would materially impact the modification and development cost, as well as stretch out the AAP program schedules (possibly 4 to 6 months longer). A second way to alleviate the above interference problems with the LM structure is to delete experiments S-01s, T-021, and T-027 from the AAP-2/AAP-3 and AAP-4 flight missions.</p>	
NASA Contractual Obligations	<p>The NASA customer is presently committed to purchase engineering, manufacturing and other technical support services from the AM prime contractor at approximately \$900,000.00 per month. It is highly probable that the AM contractor would be selected by NASA to implement the SAL installation if NASA did not choose to perform the modification and installation at the MSFC facility, since NASA is already paying for engineering and manufacturing services. Alternate position 1 locates the SAL on the Airlock Module's STS section. It is anticipated that the contractor would modify the STS assembly, make the required SAL installation, and initiate pertinent engineering changes. It is estimated that the total overall modification, SAL installation, and support cost would be \$668,175.00, or approximately 18 percent less than the normalized case (alternate position 2).</p>	<p>The same contractual comments and conditions as specified in alternate position 1 are applicable to alternate position 2. However, it is estimated that the total overall modification, SAL installation, and support cost would be \$819,000.00.</p>	<p>The National Aeronautics and Space Administration designed and fabricated the MDA at the MSFC facility. If the SAL is located at alternate position 3, it is likely that MSFC will accomplish the modification of the MDA structure, make the required installations, and initiate the engineering changes. If MSFC implements the SAL installation in-house, then the total overall modification and support cost is estimated at \$368,907.50, or approximately 55 percent less than alternate position 2. Conversely, if NASA selects the AM prime contractor to do the above work, then it is anticipated that the estimated total overall cost would be \$564,702.50, or approximately 31 percent less than the normalized case as given in alternate position 2.</p> <p>The above cost estimate figures are representative of engineering and management design considerations and do not fully consider the important operational disadvantages or expectations. It was shown under the preceding requirements and decision criteria heading (Use During AAP-3/AAP-4 Mission, Alternate Position 3) that the operational mission support requirements were seriously compromised. Further, it was shown that the interference and operational problems could be alleviated if the decision maker was willing to live within certain constraints, or</p>	<p>The same contractual comments and conditions as specified in alternate position 3 are directly applicable to alternate position 4, with the exception of the total overall cost estimates for both MSFC and a contractor. If MSFC elected to accomplish the job, then it is estimated that the total overall cost of modification, SAL installation, and support would be \$208,770.00, or approximately 74 percent less than the normalized case. If NASA chose to issue the above task to a contractor (probably the AM prime contractor) it would cost NASA about \$335,335.00, or approximately 59 percent less than the normalized case.</p> <p>The above cost estimate figures are representative of engineering and management design considerations and do not fully consider the important operational disadvantages as stated in the preceding requirement and decision criteria heading (Use During AAP-3/AAP-4 Mission, Alternate Position 3). It is reasonably thought that the selection of the SAL at alternate position 4 would be the least likely selection to meet the mission operational support requirements. Assuming that the decision maker chose to solve the operational problems by implementing the action as stated in NASA Contractual Obligations, Alternate Position 3, then it is</p>

TABLE A-4. (Concluded)

Requirement and Decision Criteria	Matrix of Alternatives			
	SAL Alternate Position No. 1	SAL Alternate Position No. 2	SAL Alternate Position No. 3	SAL Alternate Position No. 4
			<p>a greater outlay of labor, material, and time to solve the above problems could be afforded. Assuming that the decision maker chose to solve the operational problems by either developing or adapting a better electro-mechanical extension rod device to be interfaced to the MDA/SAL, then it is conservatively estimated that an additional \$750,000.00 must be expended by MSFC. The cost could conceivably reach as high as \$1,125,000.00 if a private contractor were to design, fabricate, and interface an omnidirectional extension rod to the MDA/SAL at position 3, or make additional structural modification changes.</p>	<p>conservatively estimated that an additional \$1,000,000.00 must be expended by MSFC. The cost could conceivably reach as high as \$1,125,000.00 if a private contractor were to design, fabricate, and interface an omnidirectional extension rod to the MDA/SAL at position 3, or make additional structural modification changes.</p>

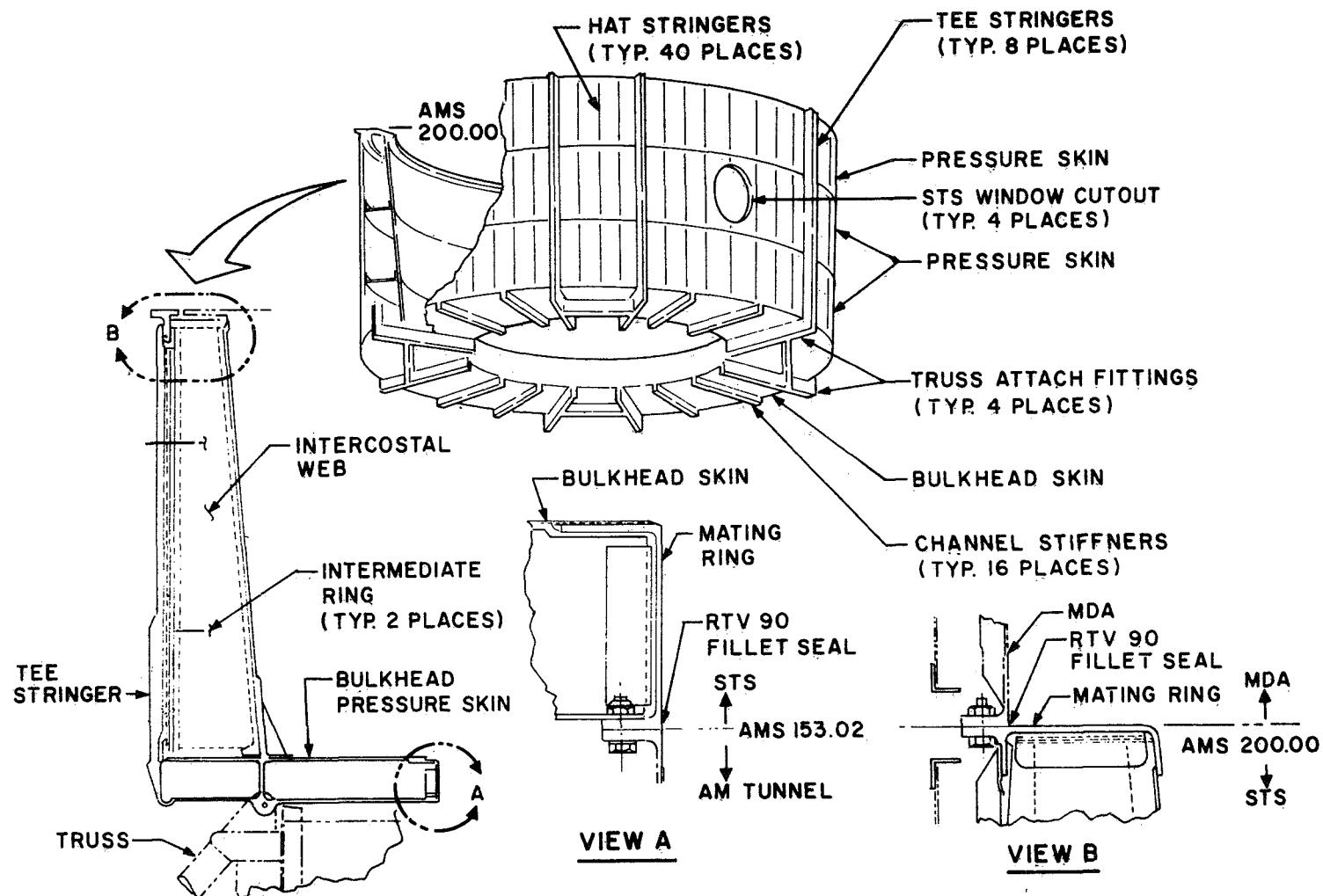


Figure A-2. Structural Transition Section with radiator removed (Reference 30).

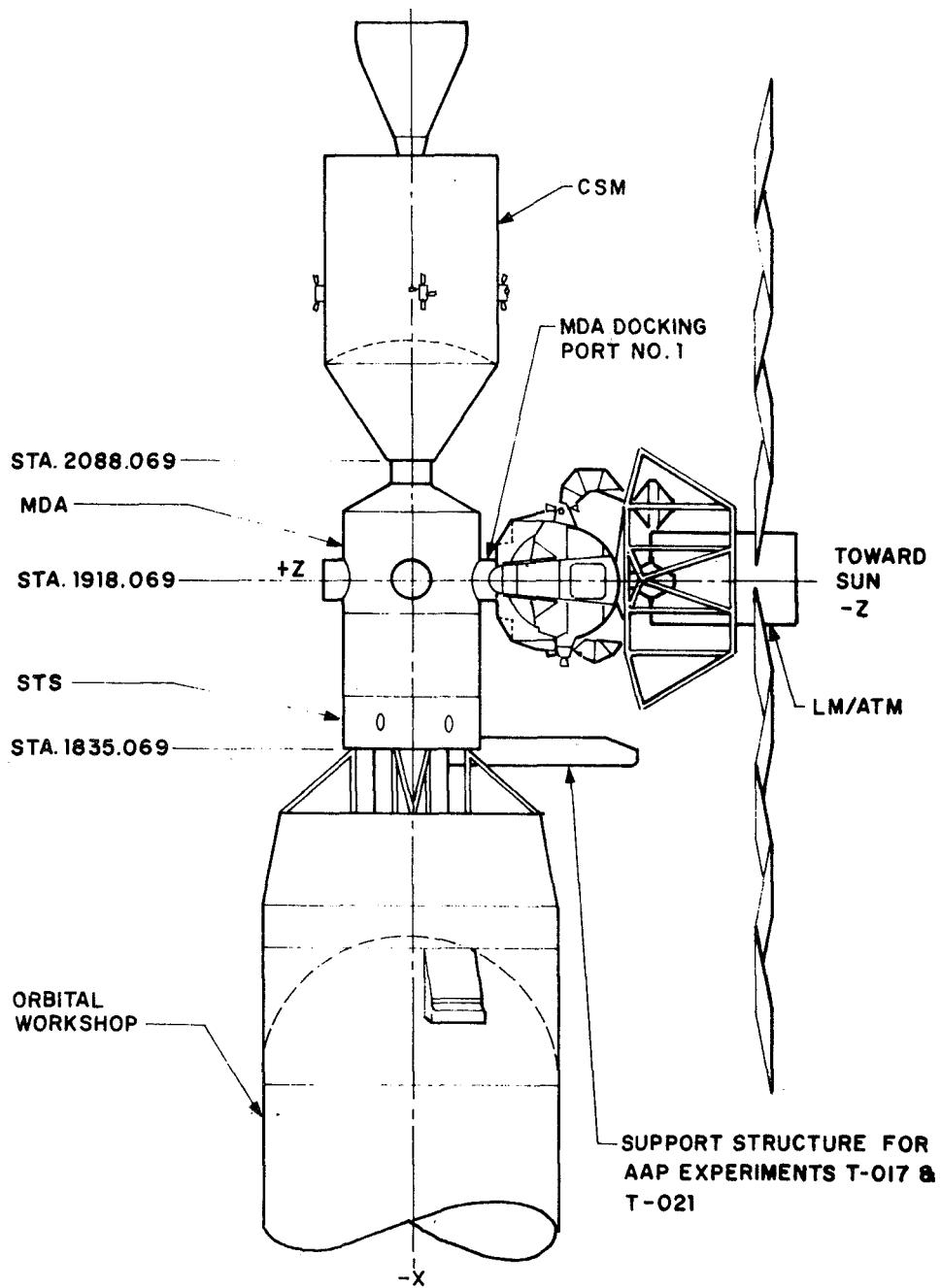
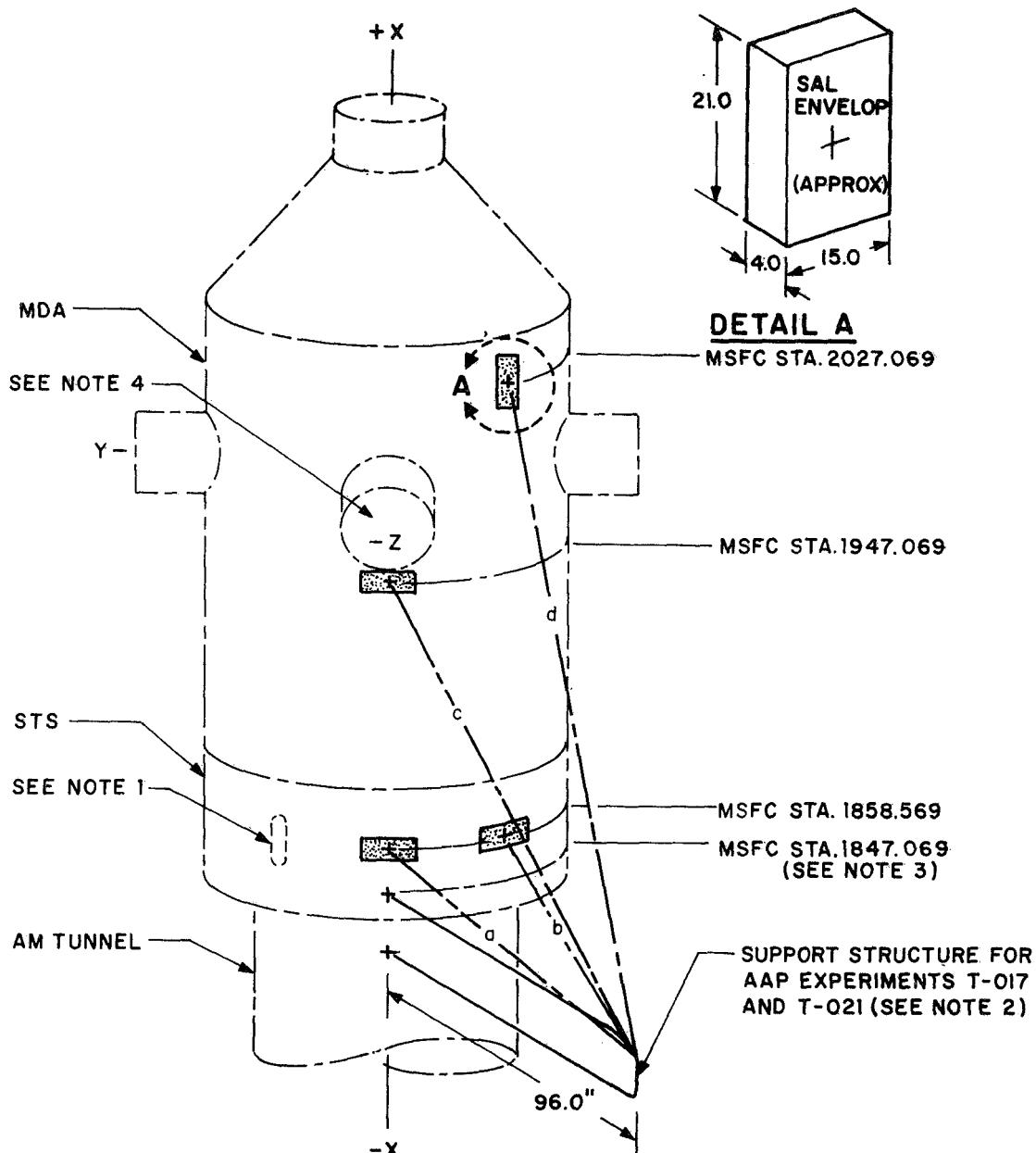


Figure A-3. Orbital Assembly arrangement for AAP experiments T-017 and T-021 (general).

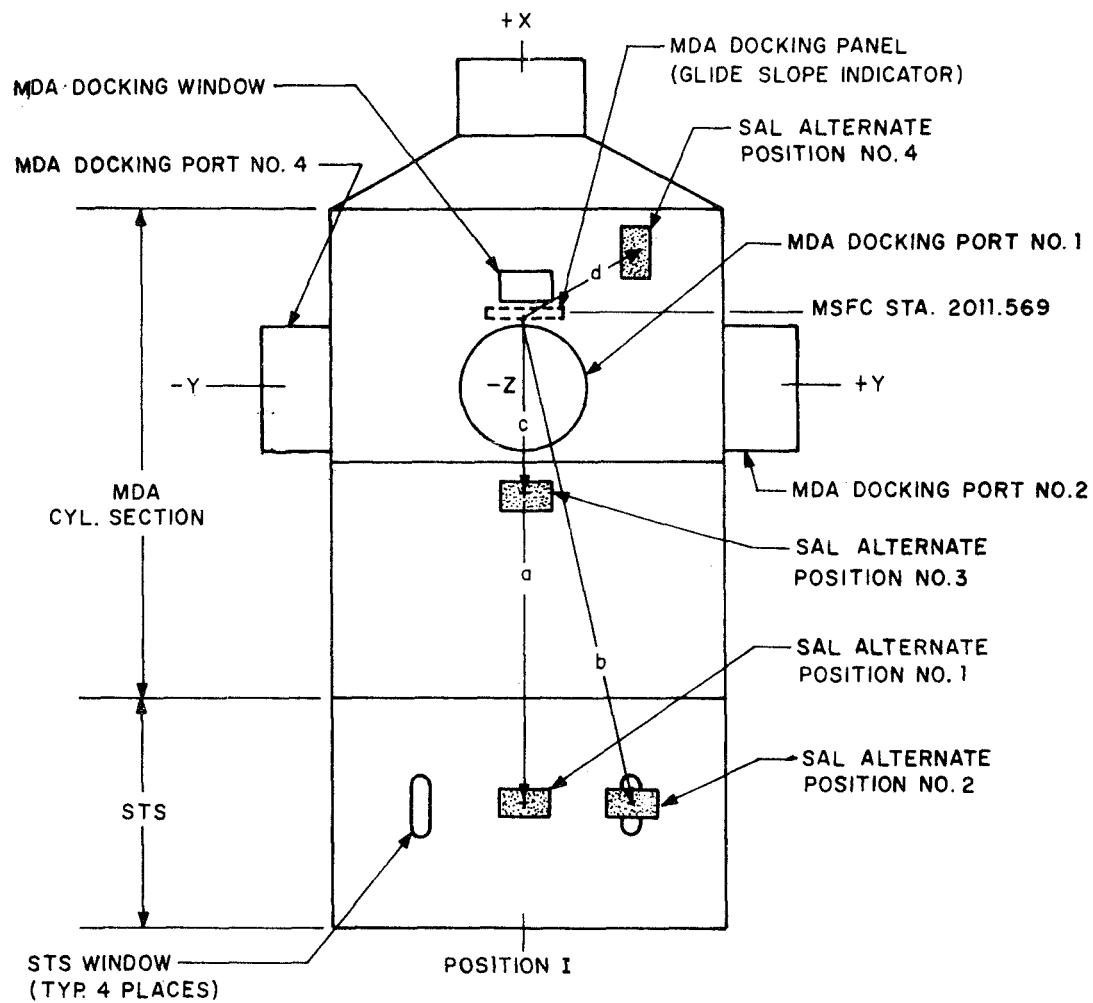


NOTES

1. STS WINDOWS (TYPICAL 4 PLACES) REMOVED FOR CLARITY
2. SUPPORT STRUCTURE PIVOTED FOR ILLUSTRATION PURPOSES.
3. MSFC STA. 1847.069 WAS INTERPOLATED
4. LM/ATM MODULES REMOVED FOR CLARITY

DISTANCE FROM SAL POSITION	REFERENCE LINE	TO O/B END OF SUPPORT STRUCTURE
1	a	96.75 IN.
2	b	121.75 IN.
3	c	138.56 IN.
4	d	217.00 IN.

Figure A-4. Orbital Assembly arrangement for AAP experiments T-017 and T-021 (detail).



LINE OF SIGHT DISTANCE FROM SAL POSITION	REFERENCE LINE	TO MDA DOCKING PANEL CONTROL STATION
1	a	153.00
2	b	159.00
3	c	64.60
4	d	46.25

Figure A-5. Location of MDA docking panel and glide-slope indicator.

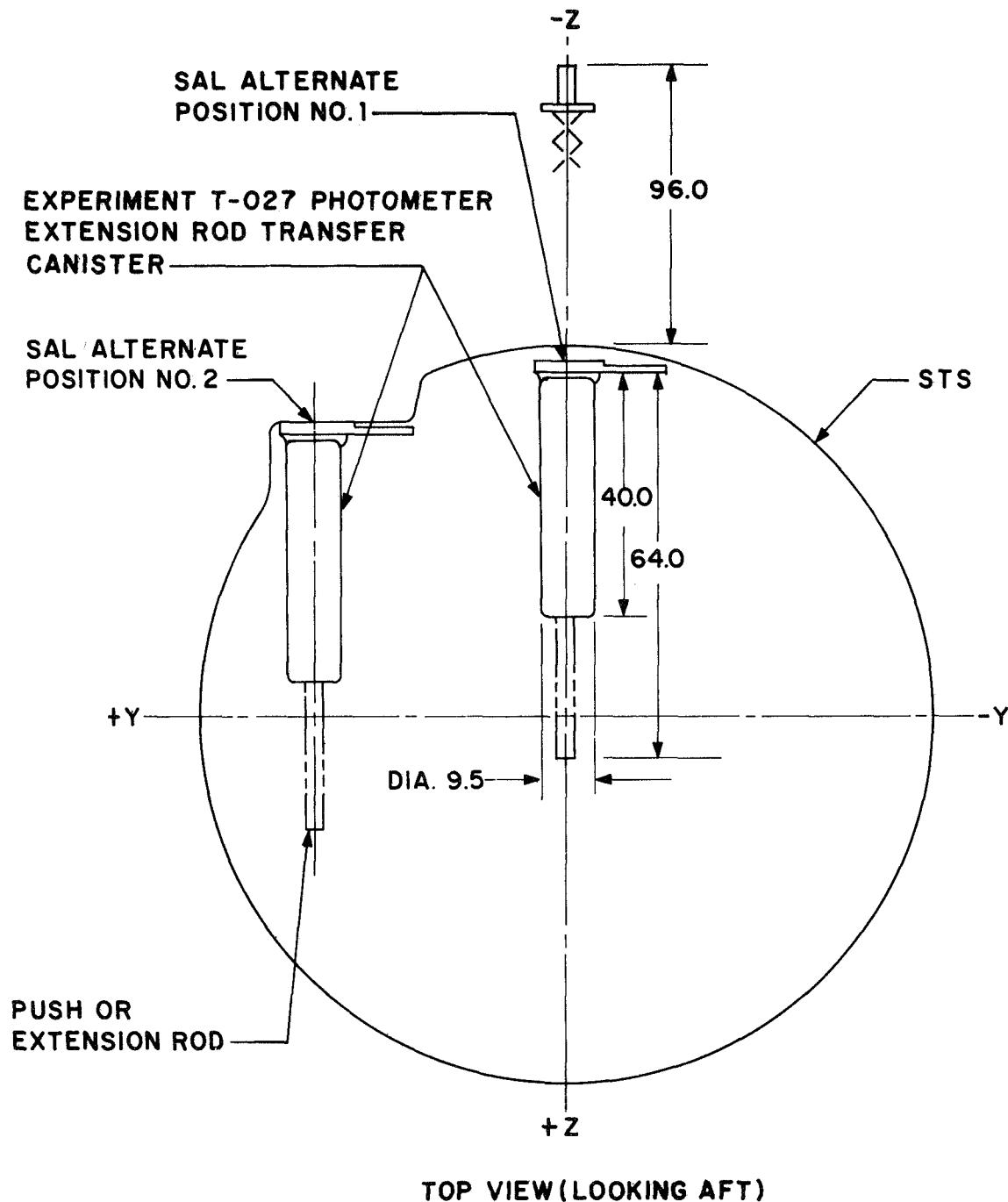


Figure A-6. SAL and photometer canister interface installation at alternate positions 1 and 2.

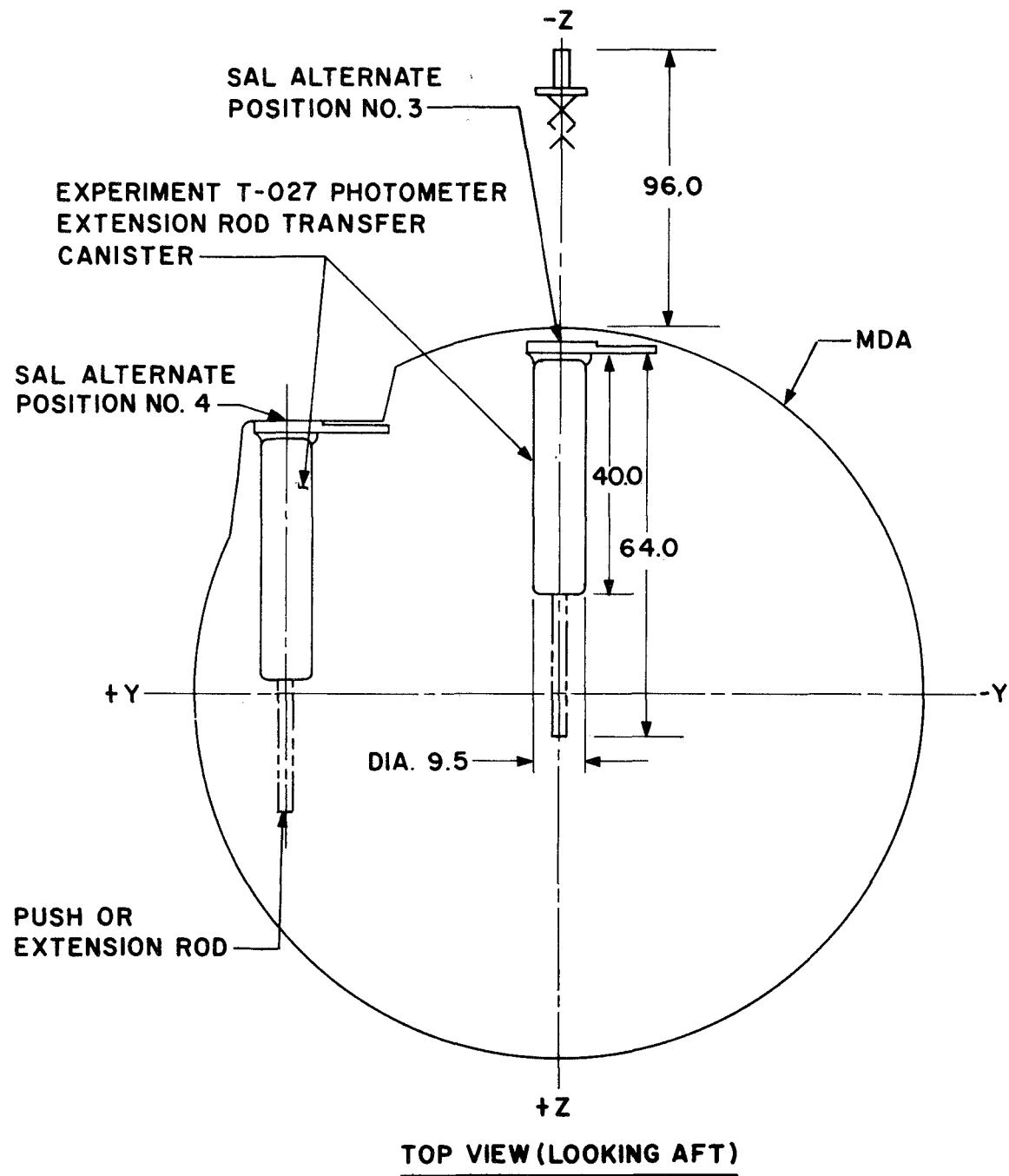


Figure A-7. SAL and photometer canister interface installation at alternate positions 3 and 4.

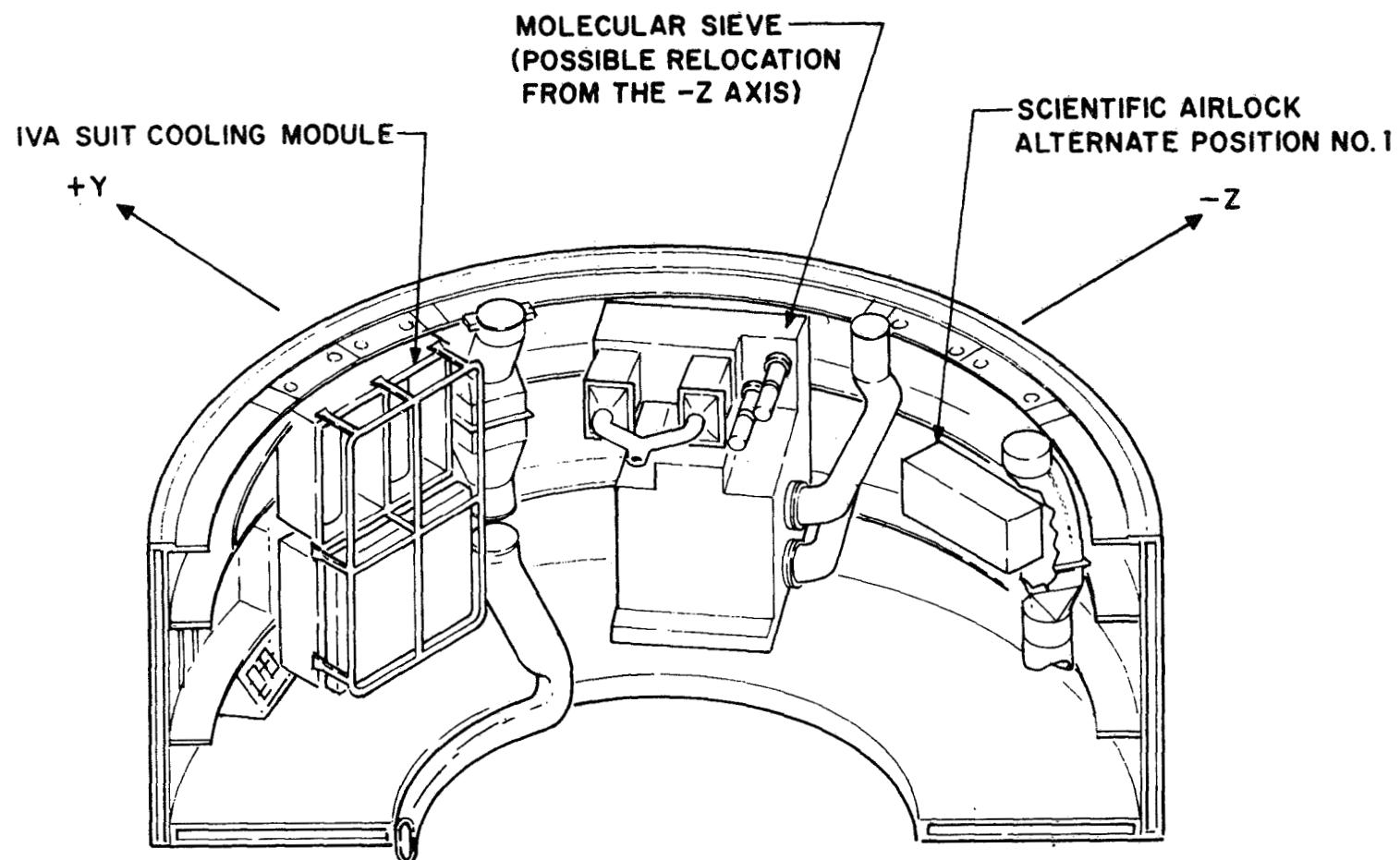


Figure A-8. Scientific Airlock/STS cutaway alternate position 1.

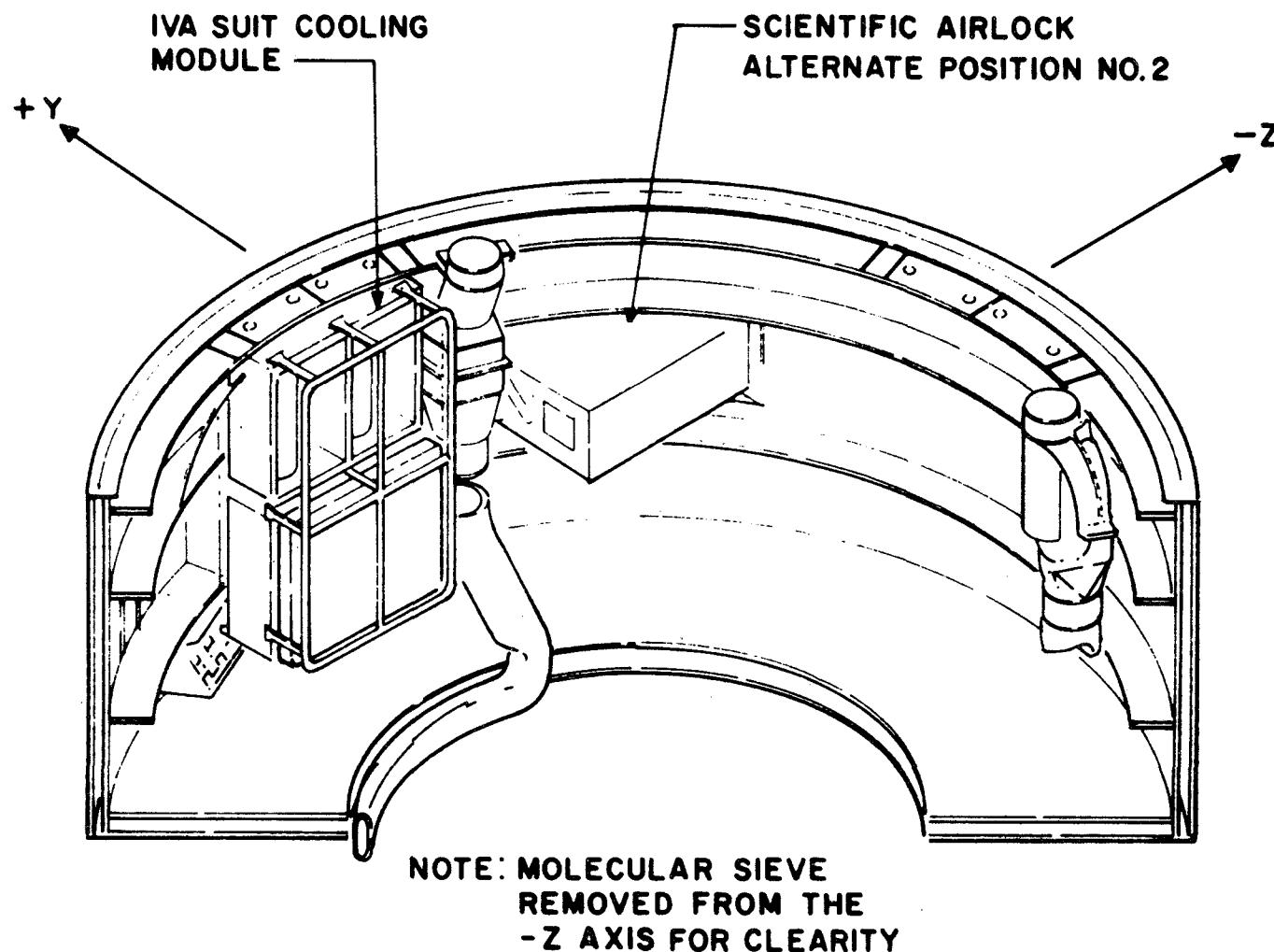


Figure A-9. Scientific Airlock/STS cutaway alternate position 2.

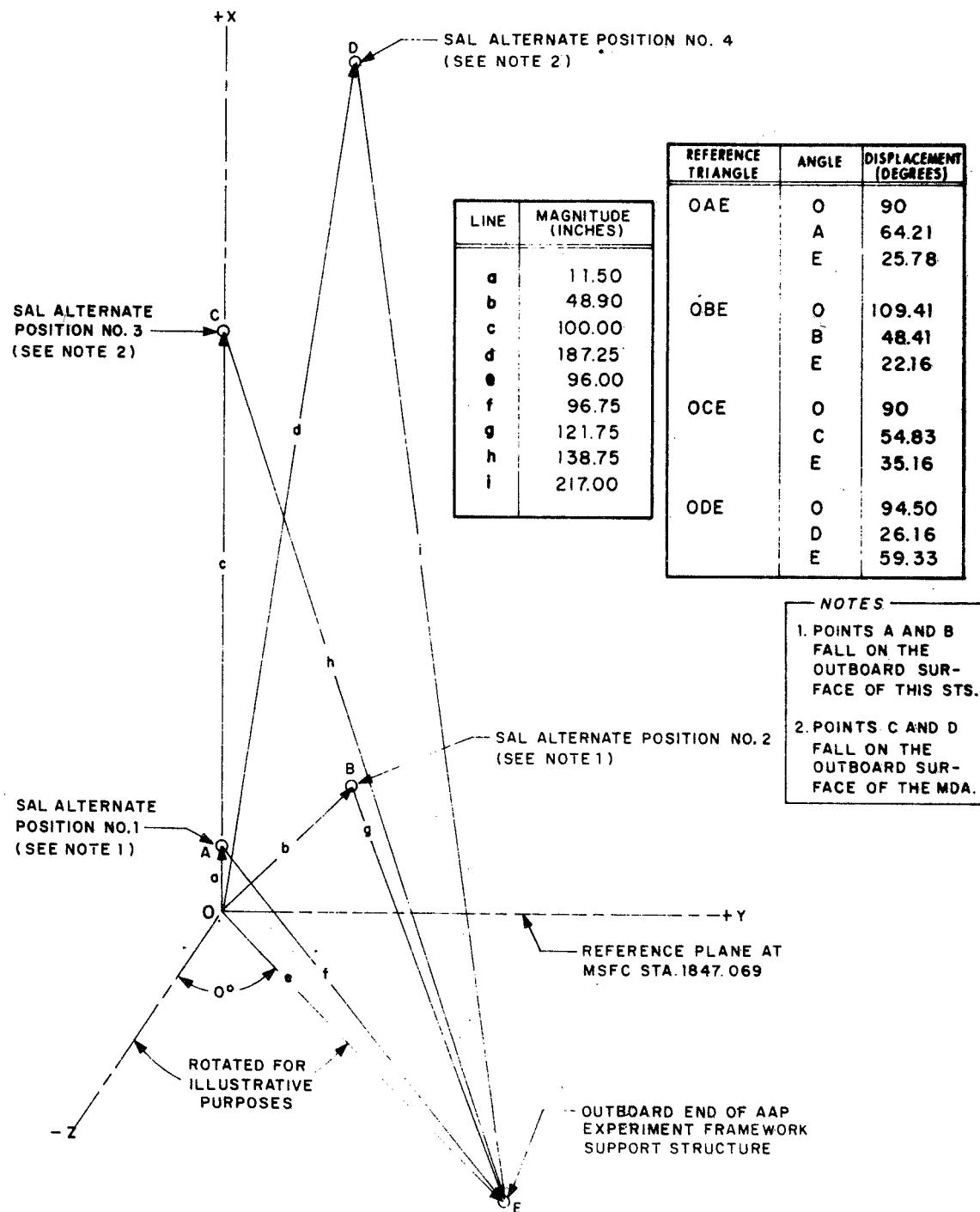


Figure A-10. SAL alternate position and experiment support structure vector relationships.

TABLE A-5. SAL MASTER DECISION MATRIX

		STATES OF NATURE	
		1	2
SAL Alternate Position No.		MSFC	Contractor
		1	C <sub>11</sub>
ACTS	2		C <sub>12</sub>
	3		C <sub>21</sub>
	4		C <sub>22</sub>
			C <sub>31</sub>
			C <sub>32</sub>
			C <sub>41</sub>
			C <sub>42</sub>

TABLE A-6. ASSESSMENT OF ADVERSE CONSEQUENCES (C<sub>11</sub>) FOR SAL ALTERNATE POSITION 1

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	Moderate: Molecular sieve and storage packages must be relocated.	0.030
Operational Performance	No problems anticipated.	0.100
Capital	High: Assuming that MSFC could accomplish the modification and installation of the SAL using the contractor's total overall cost estimate (Table B-1, AM/STS, Alternate Position 1) less the expected profit that would be awarded to an aerospace contractor.	0.025
Time	Long Duration	0.025
Philosophy	Good: Offers excellent chance of being accepted by MSFC Project Management.	0.070
		Net: 0.250

TABLE A-7. ASSESSMENT OF ADVERSE CONSEQUENCES ( $C_{12}$ ) FOR  
SAL ALTERNATE POSITION 1

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	Moderate: Same as $C_{11}$ .	0.035
Operational Performance	No problems anticipated.	0.100
Capital	High	0.020
Time	Moderate Duration	0.045
Philosophy	Best: Offers greatest chance of being accepted by MSFC Project Management if the cost factor is deemed reasonable.	0.100
	Net:	0.300

TABLE A-8. ASSESSMENT OF ADVERSE CONSEQUENCES ( $C_{21}$ ) FOR  
SAL ALTERNATE POSITION 2

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	Minor: Storage packages must be relocated.	0.040
Operational Performance	Minor: Extension rods for servicing AAP experiments T-017 and T-021 are impacted. Extension rods must either be redesigned or the length increased to fulfill AAP mission requirements.	0.060
Capital	Very High: Assuming that MSFC could accomplish the modification and installation of the SAL using the normalized total overall cost estimate less the expected profit that would be awarded to an aerospace contractor.	0.015
Time	Maximum Duration per schedule impact estimate, and could even extend beyond original estimate.	0.020
Philosophy	Good: Still offers an excellent chance of being accepted by MSFC Project Management, because the impact to the AAP experiment mission requirements is minor.	0.040
	Net:	0.175

TABLE A-9. ASSESSMENT OF ADVERSE CONSEQUENCES (C<sub>22</sub>) FOR  
SAL ALTERNATE POSITION 2

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	Minor: Same as C <sub>21</sub> .	0.045
Operational Performance	Minor: Same as C <sub>21</sub> .	0.060
Capital	Highest: Offers maximum capital risk. (Refer to normalized case.)	0.010
Time	Maximum Duration per schedule impact estimate.	0.025
Philosophy	Acceptable: If MSFC Project Management is willing to accept the cost risk and engineering redesign effort, then this outcome is still a good choice because the impact to the AAP experiment mission requirements is minor.	0.060
		Net: 0.200

TABLE A-10. ASSESSMENT OF ADVERSE CONSEQUENCES ( $C_{31}$ ) FOR  
SAL ALTERNATE POSITION 3

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	Minor: Storage packages must be relocated.	0. 010
Operational Performance	Very High: Extremely difficult to service AAP experiments T-017 and T-021. Complete redesign of extension rod service system AAP experiments is necessary. Relocating structural framework assembly within immediate vicinity of SAL alternate position 3 would not accomplish any useful purpose.	0.005
Capital	Moderate	0.010
Time	Maximum Duration per schedule impact estimate.	0.005
Philosophy	Poor: MSFC Project Management will recognize the fact that SAL alternate position 3 does not easily support the AAP experiment mission requirements. Either the AAP experiment requirements must be relaxed, or a better SAL alternate position must be relocated.	0.020
	Net:	0.050

TABLE A-11. ASSESSMENT OF ADVERSE CONSEQUENCES (C<sub>32</sub>) FOR  
SAL ALTERNATE POSITION 3

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	Minor: Same as C <sub>31</sub> .	0.010
Operational Performance	Very High: Same as C <sub>31</sub> .	0.005
Capital	Moderately High	0.004
Time	Maximum Duration per schedule impact estimate, and possibly longer because of interfacility transportation problems.	0.002
Philosophy	Very Poor: Same as C <sub>31</sub> , with even a greater risk of capital and time.	0.004  Net: 0.025

TABLE A-12. ASSESSMENT OF ADVERSE CONSEQUENCES (C<sub>41</sub>) FOR  
SAL ALTERNATE POSITION 4

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	No Problems Anticipated and has the characteristic of being the position that requires the least modification and installation effort.	0.100
Operational Performance	Unacceptable: Cannot meet AAP experiment servicing support requirements for T-017 and T-021.	-0.100
Capital	Least Cost	0.100
Time	Minimum as per schedule impact estimate.	0.100
Philosophy	Unacceptable: Cannot fulfill AAP-3/AAP-4 mission requirements. Either the experiment framework support structure must be relocated from its present position, or devise a new way for servicing the above AAP experiments.	-0.200
		Net: 0.000

TABLE A-13. ASSESSMENT OF ADVERSE CONSEQUENCES (C<sub>42</sub>) FOR  
SAL ALTERNATE POSITION 4

Critical Risk Factors	Relative Risk	Probability of Success (Est.)
Engineering Feasibility	No Problems Anticipated (same as C <sub>41</sub> ).	0.100
Operational Performance	Unacceptable: Cannot meet AAP experiment servicing support requirements for T-017 and T-021.	-0.100
Capital	Minimum	0.090
Time	Minimum as per schedule impact estimate.	0.100
Philosophy	Unacceptable: (See C <sub>41</sub> ).	-0.190
		Net: 0.000

TABLE A-14. AGGREGATION OF THE DECISION'S PROBABILITY  
OF SUCCESS (Estimated)

		STATES OF NATURE	
		1	2
ACTS	SAL Alternate Position No.	MSFC ( Probability of Success)	Contractor ( Probability of Success)
	1	$C_{11} = 0.250$	$C_{12} = 0.300$
	2	$C_{21} = 0.175$	$C_{22} = 0.200$
	3	$C_{31} = 0.050$	$C_{32} = 0.025$
	4	$C_{41} = 0.000$	$C_{42} = 0.000$
$\Sigma P = 1.0$			

## APPENDIX B

### COST ANALYSIS

TABLE B-1. FINAL CONTRACTOR VERSUS MSFC COST SUMMARY (Dollars)

Item	AM/STS		MDA			
	Alternate Position 2	Alternate Position 1	Alternate Position 3		Alternate Position 4	
	Contractor	Contractor	MSFC	Contractor	MSFC	Contractor
Modification of MDA/STS Structure	327 600.00	209 060.00	172 680.00	233 150.00	176 010.00	224 770.00
Radiator Modification	163 800.00	94 660.00	91 900.00	104 280.00	0.00	0.00
Relocation of Hard-Mounted Equipment	245 700.00	282 555.00	98 280.00	165 847.50	30 712.50	49 140.00
Transportation	<u>81 900.00</u>	<u>81 900.00</u>	<u>2 047.50</u>	<u>61 425.00</u>	<u>2 047.50</u>	<u>61 425.00</u>
Total Overall Cost	819 000.00	668 175.00	364 907.50	564 702.50	208 770.00	335 335.00
Percentage Less than Normalized Case	Normalized Case	18.42	55.44	31.05	74.51	59.06
Normalized Case						

TABLE B-2. CONTRACTOR COST SUMMARY WORK SHEET (Dollars)

Item	AM/STS			MDA			
	Alternate Position 2 <sup>a</sup>	Alternate Position 1 <sup>b</sup>	% <sup>c</sup>	Alternate Position 3 <sup>d</sup>	% <sup>c</sup>	Alternate Position 4 <sup>e</sup>	% <sup>c</sup>
Modification of MDA - STS Structure	327 600.00	209 060.00	63.81	233 150.00	71.16	224 770.00	68.61
· Disassembly	79 000.00	47 400.00	60	47 400.00	60	47 400.00	60
· Modification Rework	83 800.00	29 330.00	35	54 470.00	65	46 090.00	55
· Testing	81 000.00	81 000.00	100	81 000.00	100	81 000.00	100
· Reassembly	83 800.00	54 330.00	60	50 280.00	60	50 280.00	60
Radiator Modification	163 800.00	91 660.00	57.78	104 280.00	63.66	0	0
· Disassembly	38 600.00	11 020.00	70	35 160.00	60	0	0
· Modification Rework	40 000.00	8 000.00	20	32 000.00	80	0	0
· Reassembly	65 200.00	15 640.00	70	37 120.00	60	0	0
Relocation of Hard-Mounted Equipment	245 700.00	282 555.00	115	163 847.50	67.5	49 140.00	20
· Analysis and Engineering	122 850.00	147 420.00	120	92 137.50	75	36 855.00	30
· Modification Rework	122 850.00	135 135.00	110	73 710.00	60	12 285.00	10
Transportation	81 900.00	81 900.00	100	61 425.00	75	61 425.00	75
· Shipment To	40 950.00	40 950.00	100	30 712.50	75	30 712.50	75
· Shipment From	40 950.00	40 950.00	100	30 712.50	75	30 712.50	75

a. Highest Cost (Normalized Case)

b. High in Cost

c. Percentage Relative to Normalized Case

d. Moderate Cost

e. Cheap in Cost

TABLE B-3. CONTRACTOR VERSUS MSFC COST SUMMARY  
WORKSHEET ( Dollars)

Item	AM/STS <sup>a</sup>			MDA <sup>b</sup>			
	Alternate Position 2 <sup>c</sup>	Alternate Position 1 <sup>d</sup>	% <sup>e</sup>	Alternate Position 3 <sup>f</sup>	% <sup>e</sup>	Alternate Position 4 <sup>g</sup>	% <sup>e</sup>
Modification of MDA/STS Structure	327 600.00	209 060.00	63.81	172 680.00	52.71	176 010.00	53.73
· Disassembly	79 000.00	47 400.00	60	35 650.00	45	35 650.00	45
· Modification Rework	83 800.00	29 330.00	35	34 520.00	40	41 900.00	50
· Testing	81 000.00	81 000.00	100	64 800.00	80	60 750.00	75
· Reassembly	83 800.00	51 330.00	60	37 710.00	45	37 710.00	45
Radiator Modification	163 800.00	94 660.00	57.78	91 900.00	56.10	0	0
· Disassembly	58 600.00	41 020.00	70	29 300.00	50	0	0
· Modification Rework	40 000.00	8 000.00	20	30 000.00	75	0	0
· Reassembly	65 200.00	45 640.00	70	32 600.00	50	0	0
Relocation of Hard-Mounted Equipment	245 700.00	282 555.00	115	98 280.00	40	30 712.50	12.5
· Analysis and Engineering	122 850.00	147 420.00	120	61 425.00	50	24 570.00	20
· Modification Rework	122 850.00	135 135.00	110	36 855.50	30	6 142.50	0.5
Transportation	81 900.00	81 900.00	100	2 047.50	0.25	2 047.50	0.25
· Shipment To	40 950.00	40 950.00	100	1 023.75	0.25	1 023.75	0.25
· Shipment From	40 950.00	40 950.00	100	1 023.75	0.25	1 023.75	0.25

a. Contractor Cost Estimate Figures

b. MSFC Cost Estimate Figures

c. Highest Cost (Normalized Case)

d. High in Cost

e. Percentage Relative to Normalized Case

f. Moderately Low in Cost

g. Cheapest in Cost

TABLE B-4. CONTRACTOR DETAIL COST WORKSHEET ( Dollars)

Item	Total Cost	Percentage
Overall Modification	1 000 000.00	100.00
Less Contractor's Profit (No Padding) <sup>a</sup>	181 000.00	18.10
Net Overall Modification	819 000.00	81.90
Modification of MDA/STS Structure	327 600.00	32.70
Radiator Modification	163 800.00	16.38
Relocation of Hard-Mounted Equipment	245 700.00	24.57
Transportation	81 900.00	8.19
	<u>Net Cost</u>	<u>Percentage</u>
Modification of MDA/STS Structure	327 000.00	—
· Disassembly	79 000.00	24.16
· Modification Rework	83 800.00	25.58
· Testing	81 000.00	24.73
· Reassembly	83 800.00	25.58
<u>Disassembly</u>	79 000.00	—
· Labor	37 500.00	47.47
· Material	2 000.00	2.53
· Facility Support	10 000.00	12.66

a. Could be realized as a cost savings if MSFC accomplished the overall modification effort.

TABLE B-4. (Continued)

Item	Total Cost	Percentage
• Overhead	29 500.00	37.34
<u>Modification Rework</u>	83 800.00	—
• Labor	25 800.00	30.79
• Material	19 000.00	22.67
• Facility Support	19 000.00	22.67
• Overhead	20 000.00	23.87
<u>Testing</u>	81 000.00	—
• Labor	21 000.00	25.93
• Material	12 000.00	14.82
• Facility Support	35 000.00	43.21
• Overhead	13 000.00	16.05
<u>Reassembly</u>	83 800.00	—
• Labor	39 000.00	46.54
• Material	10 000.00	11.93
• Facility Support	10 900.00	13.10
• Overhead	23 900.00	28.52
<u>Radiator Modification</u>	163 800.00	—
• Disassembly	58 600.00	35.78
• Modification Rework	40 000.00	24.42

TABLE B-4 (Continued)

Item	Net Cost	Percentage
• Reassembly	65 200.00	39.81
<u>Disassembly</u>	58 600.00	—
• Labor	25 950.00	44.28
• Material	4 650.00	7.94
• Facility Support	20 000.00	34.13
• Overhead	8 000.00	13.65
<u>Modification Rework</u>	40 000.00	—
• Labor	13 000.00	32.50
• Material	10 000.00	25.00
• Facility Support	9 000.00	22.50
• Overhead	8 000.00	20.00
<u>Reassembly</u>	65 200.00	—
• Labor	34 000.00	52.15
• Material	7 200.00	11.04
• Facility Support	14 000.00	21.47
• Overhead	10 000.00	15.34
Relocation of Hard-Mounted Equipment	245 700.00	—
• Analysis and Engineering	122 850.00	50.00
• Modification Rework	122 850.00	50.00

TABLE B-4. (Continued)

Item	Net Cost	Percentage
<u>Analysis and Engineering</u>	122 850.00	—
• Labor	61 775.00	50.29
• Material	0.00	0.00
• Facility Support	20 358.33	16.57
• Overhead	40 716.67	33.14
<u>Modification Rework</u>	122 850.00	—
• Labor	57 850.00	47.09
• Material	28 000.00	22.79
• Facility Support	12 000.00	9.77
• Overhead	25 000.00	20.35
Transportation	81 900.00	—
• Shipment To	40 950.00	50.00
• Shipment From	40 950.00	50.00
<u>Shipment To</u>	40 950.00	—
• Labor	22 350.00	54.58
• Facility Support	5 000.00	12.21
• Overhead	13 600.00	33.21

TABLE B-4. (Concluded)

Item	Net Cost	Percentage
<u>Shipment From</u>	40 950.00	_____
• Labor	22 350.00	54.58
• Facility Support	5 000.00	12.21
• Overhead	13 600.00	33.21

TABLE B-5. NORMALIZE DETAIL COST WORKSHEET  
FOR ALTERNATE POSITION 2 (Dollars)

Item	Total Cost
Overall Modification At Position 2	819 000.00
· Labor	360 575.00
· Material	92 850.00
· Facility Support	160 258.33
· Overhead	<u>205 316.67</u>
	819 000.00
	<u>Net Cost</u>
Modification of MDA/STS Structure	327 600.00
· Labor	123 300.00
· Material	43 000.00
· Facility Support	74 900.00
· Overhead	<u>86 400.00</u>
	327 600.00
Radiator Modification	163 800.00
· Labor	72 950.00
· Material	21 850.00
· Facility Support	43 000.00
· Overhead	<u>26 000.00</u>
	163 800.00

TABLE B-5. (Concluded)

Item	Net Cost
Relocation fo Hard-Mounted Equipment	245 700.00
• Labor	119 625.00
• Material	28 000.00
• Facility Support	32 358.33
• Overhead	<u>65 716.67</u>
	245 700.00
Transportation	81 900.00
• Labor	44 700.00
• Facility Support	10 000.00
• Overhead	<u>27 200.00</u>
	81 900.00

## APPENDIX C

### WORKSHEETS AND DATA

TABLE C-1. SOLUTION ATTRIBUTE EMPHASIS COEFFICIENT RANKING WORKSHEET

Solution Attributes		Decisions													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	Modification of the Structure	.8 .0	.7 .1	.9 .0	.8 .0	.6 .1	.6 .1	.7 .1	.6 .1	.7 .1	.5 .1	.5 .1	.5 .1	.2 .1	.1 .0
B	Radiator Modification	.3 .1	.7 .0	.8 .0	.5 .2	.5 .1	.5 .1	.4 .1	.6 .1	.8 .2	.4 .2	.3 .2	.1 .1	.1 .0	
C	Relocation of Internal Equipment	.8 .1	.8 .1	.5 .1	.4 .1	.6 .3	.6 .1	.6 .2	.7 .1	.5 .1	.5 .1	.5 .1	.2 .0	.1 .0	
D	Launch Storage Area Available Over SAL	.2 .1	.2 .0	.3 .0	.2 .1	.3 .1	.2 .1	.2 .1	.2 .1	.2 .1	.2 .0	.2 .1	.1 .0		
E	Wall Area Consummed by SAL	.2 .1	.2 .2	.3 .1	.1 .0	.2 .0	.2 .0	.1 .0	.2 .0	.1 .0	.2 .0	.1 .0		.1 .0	
F	Reflection and Outgassing from T-017/T-021 Experiment	.5 .1	.7 .2	.3 .2	.5 .2	.5 .2	.7 .1	.3 .2	.3 .0	.1 .0					
G	Crew Obstructions	.6 .3	.4 .1	.5 .2	.4 .1	.4 .1	.4 .1	.2 .1	.1 .1						
H	Near Control Station	.2 .3	.3 .1	.4 .1	.4 .1	.4 .2	.4 .1	.1 .0							
I	SAL Extension Rod Clearance	.6 .2	.7 .1	.2 .1	.1 .0										
J	Transportation	.4 .1	.3 .0	.2 .0	.1 .0										
K	Schedule Effect -- SAL Installation														
L	Schedule Effect -- AAP-2 Mission														
M	Use During AAP-3/AAP-4 Mission														
N	NASA Contractual Obligations and Cost														

TABLE C-2. SOLUTION ATTRIBUTES INPUT DATA MATRIX

SOLUTION ATTRIBUTES	DECISIONS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 MODIFICATION OF THE STRUCTURE	0.0	0.8	0.7	0.9	0.8	0.6	0.6	0.7	0.6	0.7	0.5	0.5	0.2	0.1
2 RADIATOR MODIFICATION	0.2	0.0	0.3	0.7	0.8	0.5	0.5	0.5	0.4	0.6	0.8	0.4	0.3	0.1
3 RELOCATION OF INTERNAL STRUCTURE	0.2	0.6	0.0	0.8	0.8	0.5	0.4	0.6	0.6	0.7	0.5	0.5	0.2	0.1
4 LAUNCH STORAGE AREA	0.1	0.3	0.1	0.0	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.1
5 WALL AREA CONSUMMED BY SAL	0.2	0.2	0.1	0.7	0.0	0.2	0.2	0.3	0.1	0.2	0.2	0.1	0.2	0.1
6 REFLECTION /OUTGASSING FROM T-017/T-021	0.3	0.3	0.4	0.8	0.7	0.0	0.5	0.7	0.3	0.5	0.7	0.3	0.3	0.1
7 CREW OBSTRUCTIONS	0.3	0.4	0.3	0.7	0.6	0.4	0.0	0.6	0.4	0.5	0.4	0.4	0.2	0.1
8 NEAR CONTROL STATION	0.2	0.4	0.3	0.7	0.6	0.1	0.1	0.0	0.2	0.3	0.4	0.4	0.4	0.1
9 SAL EXTENSION ROD CLEARANCE	0.3	0.5	0.2	0.6	0.9	0.5	0.5	0.5	0.0	0.6	0.7	0.2	0.1	0.1
10 TRANSPORTATION	0.2	0.3	0.2	0.7	0.8	0.3	0.3	0.6	0.2	0.0	0.4	0.3	0.2	0.1
11 SCHEDULE EFFECT - SAL INSTALLATION	0.4	0.0	0.4	0.7	0.8	0.2	0.5	0.5	0.2	0.5	0.0	0.3	0.2	0.1
12 SCHEDULE EFFECT - AAP-2 MISSION	0.4	0.4	0.4	0.8	0.9	0.5	0.5	0.4	0.7	0.7	0.5	0.0	0.3	0.1
13 USE DURING AAP-3/AAP-4 MISSION	0.7	0.6	0.8	0.7	0.8	0.7	0.7	0.5	0.9	0.8	0.7	0.6	0.0	0.1
14 NASA CONTRACTURAL OBLIGATIONS AND COST	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

TABLE C-3. SOLUTION ATTRIBUTES EMPHASIS COEFFICIENTS RANKING

SOLUTION ATTRIBUTES	EMPHASIS COEFFICIENT	UNCERTAINTY
NASA CONTRACTURAL OBLIGATIONS AND COST USE DURING AAP-3/AAP-4 MISSION	0.12747 0.09450	0.00097 0.00549
MODIFICATION OF THE STRUCTURE	0.08461	0.00622
SCHEDULE EFFECT - AAP-2 MISSION	0.07252	0.00775
RELOCATION OF INTERNAL STRUCTURE	0.07142	0.00988
RADIATOR MODIFICATION	0.06703	0.00784
REFLECTION /OUTGASSING FROM T-017/T-021	0.06483	0.00894
SAL EXTENSION ROD CLEARANCE	0.06263	0.00934
CREW OBSTRUCTIONS	0.05824	0.01043
SCHEDULE EFFECT - SAL INSTALLATION	0.05274	0.00521
TRANSPORTATION	0.05054	0.00512
NEAR CONTROL STATION	0.04615	0.00681
WALL AREA CONSUMMED BY SAL	0.03076	0.00213
LAUNCH STORAGE AREA	0.02857	0.00170

TABLE C-4. SYSTEM COMPARISON TRADE-OFF EVALUATION WORKSHEET

		DECISIONS				A
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.5 /1	.2 /1	.1 /1	.0 /0	SOLUTION ATTRIBUTE
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.4 /1	.1 /1	.2 /0		Modification of Structure
C	MDA (ON AXIS) POSITION NO. 3			.4 /1		
D	MDA (OFF AXIS) POSITION NO. 4					D → C → A → B

		DECISIONS				B
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.3 /1	.4 /1	.1 /1	.0 /0	SOLUTION ATTRIBUTE
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.4 /1	.1 /1	.1 /0		Radiator Modification
C	MDA (ON AXIS) POSITION NO. 3			.1 /1		
D	MDA (OFF AXIS) POSITION NO. 4					D → C → B → A

TABLE C-4. (Continued)

		DECISIONS				C
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.3 .1	.4 .1	.2 .1	.0	
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.5 .1	.3 .1	.1		
C	MDA (ON AXIS) POSITION NO. 3		.2 .1			
D	MDA (OFF AXIS) POSITION NO. 4					D → B → C → A

SOLUTION ATTRIBUTE

Relocation of Internal Equipment

		DECISIONS				D
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.5 .0	.9 .0	.9 .0	.0	
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2		.9 .0	.9 .0	.0	
C	MDA (ON AXIS) POSITION NO. 3			.5 .0		
D	MDA (OFF AXIS) POSITION NO. 4					A · B → C · D

SOLUTION ATTRIBUTE

Launch Area Available Over SAL

TABLE C-4. (Continued)

		DECISIONS				SOLUTION ATTRIBUTE
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.9 .1	.5 .0	.9 .1		
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.1 .1	.5 .0			Wall Area Consumed by SAL
C	MDA (ON AXIS) POSITION NO. 3			.9 .1		
D	MDA (OFF AXIS) POSITION NO. 4					$A \cdot C \rightarrow B \cdot D$

E

		DECISIONS				SOLUTION ATTRIBUTE
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.4 .1	.3 .1	.2 .1		
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.3 .1	.2 .1			Reflection and Outgassing from T-017 and T-021 Experiments
C	MDA (ON AXIS) POSITION NO. 3			.1 .1		
D	MDA (OFF AXIS) POSITION NO. 4					$D \rightarrow C \rightarrow B \rightarrow A$

F

TABLE C-4. (Continued)

ALTERNATE POSITION SELECTION		DECISIONS				SOLUTION ATTRIBUTE
		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.2 .1	.4 .1	.1 .1	.1 .1	
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.8 .1	.4 .1	.1 .1	.1 .1	Crew Obstructions
C	MDA (ON AXIS) POSITION NO. 3			.1 .1	.1 .1	
D	MDA (OFF AXIS) POSITION NO. 4					D → B → C → A

G

ALTERNATE POSITION SELECTION		DECISIONS				SOLUTION ATTRIBUTE
		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.4 .1	.3 .1	.1 .1	.1 .1	
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.4 .1	.2 .1	.1 .1	.1 .1	Near Control Station
C	MDA (ON AXIS) POSITION NO. 3			.3 .1	.1 .1	
D	MDA (OFF AXIS) POSITION NO. 4					D → C → B → A

H

TABLE C-4. (Continued)

		DECISIONS				SOLUTION ATTRIBUTE
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.7 .1	.9 .0	.9 .0		
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.6 .1	.9 .1			SAL Extension Rod Clearance
C	MDA (ON AXIS) POSITION NO. 3		.4 .1			
D	MDA (OFF AXIS) POSITION NO. 4					$A \rightarrow B \rightarrow D \rightarrow C$

I

		DECISIONS				SOLUTION ATTRIBUTE
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.4 .2	.4 .1	.4 .1		
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2	.4 .1	.4 .1			Transportation
C	MDA (ON AXIS) POSITION NO. 3		.4 .2			
D	MDA (OFF AXIS) POSITION NO. 4					$C \cdot D \rightarrow A \cdot B$

J

TABLE C-4. (Continued)

K

ALTERNATE POSITION SELECTION		DECISIONS				SOLUTION ATTRIBUTE
		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.2 .3	.3 .1	.2 .1	.2 .1	Schedule Effect - SAL Installation
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2		.3 .1	.2 .1		
C	MDA (ON AXIS) POSITION NO. 3			.4 .1		
D	MDA (OFF AXIS) POSITION NO. 4					D → C → B → A

L

ALTERNATE POSITION SELECTION		DECISIONS				SOLUTION ATTRIBUTE
		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.4 .3	.3 .3	.4 .3	.1	Schedule Effect - AAP-2 Mission
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2		.3 .1	.2 .1		
C	MDA (ON AXIS) POSITION NO. 3			.1		
D	MDA (OFF AXIS) POSITION NO. 4					D → C → A → B

TABLE C-4. (Continued)

		DECISIONS				M
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.8 / .1	.9 / .0	.9 / .0		<u>SOLUTION ATTRIBUTE</u>
B	AIRLOCKS/STS (OFF AXIS) POSITION NO. 2		.9 / .0	.9 / .0		Use During AAP-3/AAP-4 Mission
C	MDA (ON AXIS) POSITION NO. 3			.5 / .0		
D	MDA (OFF AXIS) POSITION NO. 4					$A \rightarrow B \rightarrow C \rightarrow D$

		DECISIONS				N
ALTERNATE POSITION SELECTION		A	B	C	D	
A	AIRLOCK/STS (ON AXIS) POSITION NO. 1	.5 / .1	.9 / .0	.9 / .1		<u>SOLUTION ATTRIBUTE</u>
B	AIRLOCK/STS (OFF AXIS) POSITION NO. 2		.9 / .0	.8 / .1		NASA Contractual Obligations & Cost
C	MDA (ON AXIS) POSITION NO. 3			.5 / .0		
D	MDA (OFF AXIS) POSITION NO. 4					$A \rightarrow B \rightarrow D \rightarrow C$

TABLE C-5. SYSTEM COMPARISON TRADE-OFF INPUT DATA MATRIXES

\*\*\*\*\*

\*\*MODIFICATION OF THE STRUCTURE

1. AIRLOCK/STS ON AXIS POSITION NO. 1
2. AIRLOCK/STS OFF AXIS POSITION NO. 2
3. MDA ON AXIS POSITION NO. 3
4. MDA OFF AXIS POSITION NO. 4.

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.5	0.2	0.1
2	0.4	0.0	0.4	0.2
3	0.7	0.5	0.0	0.4
4	0.9	0.8	0.5	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*RADIATOR MODIFICATION

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.3	0.4	0.1
2	0.6	0.0	0.4	0.1
3	0.5	0.5	0.0	0.1
4	0.9	0.9	0.9	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

TABLE C-5 (Continued)

\*\*RELOCATION OF INTERNAL STRUCTURE

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.3	0.4	0.2
2	0.6	0.0	0.5	0.3
3	0.5	0.4	0.0	0.2
4	0.8	0.6	0.7	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\* LAUNCH STORAGE AREA

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.5	0.9	0.9
2	0.5	0.0	0.9	0.9
3	0.1	0.1	0.0	0.5
4	0.1	0.1	0.5	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\* WALL AREA CONSUMMED BY SAL

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.9	0.5	0.9
2	0.0	0.0	0.1	0.5
3	0.5	0.8	0.0	0.9
4	0.0	0.5	0.0	0.0

ABOVE MATRIX IS CONSISTENT

TABLE C-5 (Continued)

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*REFLECTION /OUTGASSING FROM T-017/T-021

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.4	0.3	0.2
2	0.5	0.0	0.3	0.2
3	0.6	0.6	0.0	0.1
4	0.7	0.7	0.8	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*CREW OBSTRUCTIONS

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.2	0.4	0.1
2	0.7	0.0	0.8	0.4
3	0.5	0.1	0.0	0.1
4	0.8	0.5	0.8	0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*NEAR CONTROL STATION

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.4	0.3	0.1
2	0.5	0.0	0.4	0.2
3	0.6	0.5	0.0	0.3

TABLE C-5 (Continued)

4 0.8 0.7 0.6 0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.00

\*\*\*\*\*

\*\*SAL EXTENSION ROD CLEARANCE

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

1 2 3 4

1 0.0 0.7 0.9 0.9

2 0.2 0.0 0.6 0.9

3 0.1 0.3 0.0 0.4

4 0.1 0.0 0.5 0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*TRANSPORTATION

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

1 2 3 4

1 0.0 0.4 0.4 0.4

2 0.4 0.0 0.4 0.4

3 0.5 0.5 0.0 0.4

4 0.5 0.5 0.4 0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*SCHEDULE EFFECT - SAL INSTALLATION

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

1 2 3 4

1 0.0 0.2 0.3 0.2

TABLE C-5 (Continued)

2 0.5 0.0 0.3 0.2

3 0.6 0.6 0.0 0.4

4 0.7 0.7 0.5 0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*SCHEDULE EFFECT - AAP-2 MISSION

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

1 2 3 4

1 0.0 0.4 0.3 0.4

2 0.3 0.0 0.3 0.2

3 0.4 0.6 0.0 0.4

4 0.5 0.7 0.5 0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

\*\*USE DURING AAP-3/AAP-4 MISSION

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

1 2 3 4

1 0.0 0.8 0.9 0.9

2 0.1 0.0 0.9 0.9

3 0.1 0.1 0.0 0.5

4 0.1 0.1 0.5 0.0

ABOVE MATRIX IS CONSISTENT

COEFFICIENT OF CONSISTENCY 1.000

\*\*\*\*\*

TABLE C-5 (Continued)

\*\*NASA CONTRACTURAL OBLIGATIONS AND COST

SYSTEM COMPARASION TRADEOFF INPUT DATA MATRIX

	1	2	3	4
1	0.0	0.5	0.9	0.9
2	0.4	0.0	0.9	0.8
3	0.1	0.1	0.0	0.5
4	0.0	0.1	0.5	0.0

ABOVE MATRIX IS CONSISTENT.

COEFFICIENT OF CONSISTENCY 1.000

TABLE C-5 (Continued)

## \*\*\* SYSTEM COMPARISON TRADEOFF EVALUATIONS \*\*\*

## \*MODIFICATION OF THE STRUCTURE

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.13333	0.01296
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.16666	0.01481
MDA ON AXIS POSITION NO. 3	0.26666	0.02962
MDA OFF AXIS POSITION NO. 4	0.36666	0.00925

## \*RADIATOR MODIFICATION

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.13333	0.01296
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.18333	0.01851
MDA ON AXIS POSITION NO. 3	0.18333	0.01851
MDA OFF AXIS POSITION NO. 4	0.44999	0.00000

## \*RELOCATION OF INTERNAL STRUCTURE

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.15000	0.01296
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.23333	0.02592
MDA ON AXIS POSITION NO. 3	0.18333	0.02037
MDA OFF AXIS POSITION NO. 4	0.35000	0.02407

## \* LAUNCH STORAGE AREA

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.38333	0.00000
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.38333	0.00000
MDA ON AXIS POSITION NO. 3	0.11666	0.00000

TABLE C-5 (Continued)

MDA OFF AXIS POSITION NO. 4	0.11666	0.00000
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\* WALL AREA CONSUMMED BY SAL

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.38333	0.03333
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.10000	0.00185
MDA ON AXIS POSITION NO. 3	0.36666	0.03148
MDA OFF AXIS POSITION NO. 4	0.08333	0.00000

\*REFLECTION /OUTGASSING FROM T-017/T-021

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.15000	0.01666
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.16666	0.01851
MDA ON AXIS POSITION NO. 3	0.21666	0.02407
MDA OFF AXIS POSITION NO. 4	0.36666	0.04074

\*CREW OBSTRUCTIONS

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.11666	0.01296
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.31666	0.03518
MDA ON AXIS POSITION NO. 3	0.11666	0.01296
MDA OFF AXIS POSITION NO. 4	0.35000	0.03888

\*NEAR CONTROL STATION

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.13333	0.01481
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.18333	0.02037
MDA ON AXIS POSITION NO. 3	0.23333	0.02592

TABLE C-5 (Continued)

MDA OFF AXIS POSITION NO. 4	0.35000	0.03888
-----------------------------	---------	---------

\*SAL-EXTENSION ROD CLEARANCE

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.41666	0.01296
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.28333	0.03148
MDA ON AXIS POSITION NO. 3	0.13333	0.01296
MDA OFF AXIS POSITION NO. 4	0.10000	0.00925

\*TRANSPORTATION

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.20000	0.03148
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.20000	0.03148
MDA ON AXIS POSITION NO. 3	0.23333	0.03518
MDA OFF AXIS POSITION NO. 4	0.23333	0.03518

\*SCHEDULE EFFECT - SAL INSTALLATION

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.11666	0.02354
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.16666	0.04497
MDA ON AXIS POSITION NO. 3	0.26666	0.02962
MDA OFF AXIS POSITION NO. 4	0.31666	0.03518

\*SCHEDULE EFFECT - AAP-2 MISSION

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.18333	0.05740
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.13333	0.03068
MDA ON AXIS POSITION NO. 3	0.23333	0.04708

TABLE C-5 (Concluded)

MDA OFF AXIS POSITION NO. 4	0.28333	0.03148
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\*USE DURING AAP-3/AAP-4 MISSION

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.43333	0.01481
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.31666	0.00185
MDA ON AXIS POSITION NO. 3	0.11666	0.00000
MDA OFF AXIS POSITION NO. 4	0.11666	0.00000

\*NASA CONTRACTURAL OBLIGATIONS AND COST

SYSTEM	MERIT SCORE	UNCERTAINTY
AIRLOCK/STS ON AXIS POSITION NO. 1	0.38333	0.02592
AIRLOCK/STS OFF AXIS POSITION NO. 2	0.35000	0.02222
MDA ON AXIS POSITION NO. 3	0.11666	0.00000
MDA OFF AXIS POSITION NO. 4	0.10000	0.00185

TABLE C-6. SOLUTION ALTERNATIVES PREFERENCE ANALYSIS

SYSTEM	RANK	MERIT COEFFICIENT	UNCERTAINTY
MDA OFF AXIS POSITION NO. 4	1	0.23148	0.04365
AIRLOCK/STS ON AXIS POSITION NO. 1	2	0.22183	0.03868
AIRLOCK/STS OFF AXIS POSITION NO. 2	3	0.21565	0.04124
MDA ON AXIS POSITION NO. 3	4	0.17120	0.03623

## REFERENCES

1. Churchman, C. West; Ackoff, Russel L. ; and Arnoff, El Leonard: Introduction to Operations Research. John Wiley and Sons, Inc. , New York, N. Y. , 1957.
2. Fishburn, P. C.: Decision and Value Theory. John Wiley and Sons, Inc. , New York, N. Y. , 1964.
3. Miller, D. W. and Starr, M. K.: Executive Decisions and Operations Research. Prentice-Hall, Inc. , Englewood Cliffs, N. J. , 1960.
4. Lifson, M. W.: Evaluation Technology (Class Notes from a Short Course on Evaluations of Engineered Systems). University of California Extension, Los Angeles, California, January, 1969.
5. Hall, A. D.: A Methodology for Systems Engineering. D. Van Nostrand Company, Inc. , New York, N. Y. , 1965, Chapters V, VII, VIII, X, XI, and XIII.
6. Dewey, J.: Logic, The Theory of Inquiry. Henry Holt and Co. , New York, N. Y. , 1938.
7. Copeland, B. R : Statistical Decision Theory. Management Services, May-June, 1968, pp 45-51.
8. Chestnut, H.: Systems Engineering Methods. John Wiley and Sons, Inc. , New York, N. Y. , 1967, Chapter IV, pp 135-142 and Chapter V, pp 187-190.
9. Goode, H. and Eckman, D. P. (Editor): Systems: Research and Design, Chapter VI, A Decision Model for the Fourth-Level Model in the Boulding Sense. John Wiley and Sons, Inc. , New York, N. Y. , 1961.
10. Stevens, S. S.: Handbook of Experimental Psychology. John Wiley and Sons, Inc. , New York, N. Y. , 1951.
11. Duncan, L. R. and Raiffa, H. R.: Games and Decisions. John Wiley and Sons, Inc. , New York, N. Y. , 1957, Chapters II and XIII and Chapter XIV, pp 345-353.

## REFERENCES (Continued)

12. Kepner, C. H. and Tregoe, B. B.: *The Rational Manager — A Systematic Approach to Problem Solving and Decision Making*. McGraw-Hill Book Company, New York, N. Y., 1965, Chapter III, pp 48-53, and Chapter X, pp 173-205.
13. Woodson, T. T.: *Introduction to Engineering Design*. McGraw-Hill Book Company, New York, N. Y., 1966, Chapters XII and XIII.
14. Carr, C. R. and Howe, C. W.: *Quantitative Decision Procedures in Management and Economics*. McGraw-Hill Book Company, New York, N. Y., 1964, Chapter I, pp 3-47.
15. Fowlkes, J. K.: *Of What Value is Value Analysis*. *Systems and Procedures Journal*, September/October, 1967, pp 30-33.
16. Lifson, M. W.: *Value Theory, Cost-Effectiveness: The Economic Evaluation of Engineered Systems*. University of California Extension, Los Angeles, March 18-22, 1968.
17. Dixon, J. R.: *Design Engineering: Inventiveness, Analysis and Decision Making*. McGraw-Hill Book Company, New York, N. Y., 1966, Chapter XI, and Chapter XVI, pp 327-337.
18. Bierman, H.; Bonini, C. P.; Fouraker, L. E.; and Jaedicke, R. K.: *Quantitative Analysis for Business Decisions*. Richard D. Irwin, Inc., Homewood, Ill., 1965, Chapters I, II, IV, and XIV.
19. Edwards, W. and Trevsky, A.: *Decision Making*. Penguin Books, Inc., Baltimore, Md., 1967.
20. Ackoff, R. L.: *Scientific Method: Optimizing Applied Research Decisions*. John Wiley and Sons, Inc., New York, N. Y., 1962.
21. Samuelson, P. A.: *Economics — An Introductory Analysis*. McGraw-Hill Book Company, New York, N. Y., 1961.

## REFERENCES (Concluded)

22. Savage, L. J.: The Foundation of Statistics. John Wiley and Sons, Inc. , New York, N. Y. , 1954.
23. Shelly II, M. W. and Bryan, G. L.: Human Judgements and Optimality. John Wiley and Sons, Inc. , New York, N. Y. , 1964.
24. Von Neuman, John and Morgenstern, Oscar: Theory of Games and Economic Behavior. Third Edition, Princeton University Press, Princeton, New Jersey, 1953.
25. United States Air force: Systems Engineering Management Procedures. (AFSCM 375-5) , March 10, 1966.
26. Fasal, J.: Forced Decisions for Value. Product Engineering, April 12, 1965, pp 84-86.
27. Moroney, M. J.: Facts from Figures. Penguin Books, Baltimore, Md. , 1963, Chapter XVIII, pp 334-353.
28. Stevens, S. S.: Measurement, Psychophysics, and Utility. Measurement — definitions and theories. Edited by Churchman, C. W. and Ratoosh, P. , John Wiley and Sons, Inc. , New York, N. Y. , 1959.
29. MSFC drawing 10M12999. ( Sheets 1, 2, and 4) , MDA Assembly Layout.
30. Airlock Design Data Book. McDonnell Douglas, December 15, 1967.
31. MSFC drawing 10M16112, Structural Transition Section Equipment Assembly Modification Mockup.
32. Platt, G. K.: AAP-1 through AAP-4 Baseline Configuration Definition Document. R-P&VE-XA-68-127, October 3, 1968, p 35.

## BIBLIOGRAPHY

Alchian, Armen A.: The Meaning of Utility Measurement. *The American Economic Review*, 53, 26-50, March, 1953.

Alexis, M. and Wilson, C. Z.: *Organizational Decision Making*, Prentice-Hall, Englewood Cliffs, New Jersey, 1967.

Alger, John R. M. and Hays, Carl V.: *Creative Synthesis in Design*. Prentice-Hall, Englewood Cliffs, New Jersey, 1964.

Asimow, M.: *Introduction to Design*. Prentice-Hall, Englewood Cliffs, New Jersey, 1962 (Paperback).

Barish, Norman N.: *Economic Analysis for Engineering and Managerial Decision-Making*. McGraw-Hill, New York, N. Y., 1962.

Borel, Emile: *Probability and Certainty*. Walker & Company, New York, N. Y., 1963.

Borck, D.: Decision Theory: An Operations Research Tool. *Systems and Procedures Journal*, May/June, 1968, pp. 24-26.

Borsk, E. C. and Chapman, J. F.: *New Decision-Making Tools for Managers*. Harvard University Press, Cambridge, Mass., 1963.

Chernoff, H. and Moses, L. E.: *Elementary Decision Theory*. John Wiley and Sons, Inc., New York, N. Y., 1959.

Cooper, J. D.: *The Art of Decision Making*. Doubleday, Inc., Garden City, New Jersey, 1961.

Davidson, Donald and Suppes, Patrick: *Decision Making — An Experimental Approach*. Stanford University Press, Stanford, California, 1957.

Eckenrode, R. T.: Weighting Multiple Criteria. *Management Science*, November, 1965.

Eddison, R. T.; Pennycuick, K.; and Rivett, B. H. P.: *Operational Research in Management*. John Wiley and Sons, Inc., New York, N. Y., 1962.

## BIBLIOGRAPHY (Continued).

Ellis, D. O. and Ludwig, F. J.: Systems Philosophy — Human Subsystems. Section 3-3, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1962.

Ericson, W. A.: Decision Making Under Uncertainty. University of Michigan Engineering Summer Conferences, Ann Arbor, Michigan, June 17-28. 1968.

Gagne', R. M.: Psychological Principles in System Development. Holt, Rinehart and Winston, New York, N. Y., 1965.

Gregory, S. A.: The Design Method. Plenum Press, New York, N. Y., 1966.

Hein, L. W.: The Quantitative Approach to Managerial Decisions. Prentice-Hall, Englewood Cliffs, New Jersey, 1967.

Heyel, C.: The Encyclopedia of Management. Reinhold Publishing Corporation, New York, N. Y., 1963.

Hitch, C. J.: Decision Making for Defense. University of California Press, Los Angeles, Calif., 1966.

Johnson, R. A.; Kast, F. E.; and Rosenyweig, J. E.: The Theory and Management of Systems, McGraw-Hill Book Company, New York, N. Y., 1967.

Jones, M. H.: Executive Decision Making. R. D. Irwin, Inc., Homewood, Illinois, 1962.

Kline, M. B.: Decision Theory, Cost-Effectiveness: The Economic Evaluation of Engineered Systems. University of California Extension, Los Angeles, Calif., March 18-22, 1968.

Machol, R. E.; Tanner, W. P.; and Alexander, S. N.: Systems Engineering Handbook. McGraw-Hill Book Company, New York, N. Y., 1965.

Miller, D. W. and Star, M. K.: The Structure of Human Decisions. Prentice-Hall, Englewood Cliffs, New Jersey, 1967.

## BIBLIOGRAPHY (Concluded)

Milnor, John: Games Against Nature. Decision Processes, Edited by R. M. Thrall, C. H. Coombs, and R. L. Davis, John Wiley and Sons, Inc., New York, N. Y., 1954.

Peters, W. and Summers, G.: Statistical Analysis for Business Decisions. Prentice-Hall, Englewood Cliffs, New Jersey, 1968.

Richmond, S. B.: Operations Research for Management Decisions. Ronald Press Co., New York, N. Y., 1968.

Schermerhorn, R. S. and Taft, M. I.: Measuring Design Intangibles. Machine Design, December 19, 1968.

Schermerhorn, R. S. and Taft, M. I.: Minimizing Risk Factors in Design. Machine Design, January 9, 1969.

Schermerhorn, R. S. and Taft, M. I.: Utility Theory in Design. Machine Design, February 6, 1969.

Shepard, R. N.: On Subjectively Optimum Selection Among Multiattribute Alternatives. Human Judgments and Optimality, Edited by Shelly, M. W. and Bryan, G. L., John Wiley and Sons, Inc., New York, N. Y., 1964.

Shuchman, A.: Scientific Decision Making in Business. Holt, Rinehart and Winston, Inc., New York, N. Y., 1963.

Vance, S.: Management Decision Simulation. McGraw-Hill Book Company, New York, N. Y., 1960.

## APPROVAL

# A SYSTEMS ENGINEERING DECISION ALGORITHM WITH APPLICATION TO APOLLO APPLICATIONS PROGRAM INTEGRATION PROBLEMS

By C. E. DeSanctis

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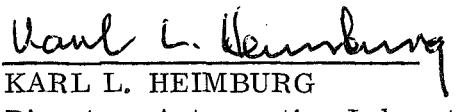
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